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AN INTRODUCTION TO HUMAN FACTORS FOR ENGINEERING MANAGERS: FRAMEWORK FOR A TEACHING UNIT

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The materials provided in this document represent an attempt to capture and convey in a concise way some of the basic characteristics of human factors work that managers of military system development projects need to know so that such managers can do their jobs more effectively. A framework is presented that can be used in the planning and presentation of a short course or workshop, or that can be used as a unit in a sustained program of instruction.

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HUMAN FACTORS INSTRUCTIONAL MATERIALS

General Introduction

Those individuals who are assigned the management responsibilities for the procurement of major systems by one or another of the military services confront a challenge that grows more complicated every day that passes. For example, the structure of priorities has become a source of confusion. Is the primary goal still the achievement of superior weapon lethality by the application of advanced technology or should a potential technological edge be sacrificed to achieve a higher level of durability? Is this presumptive trade-off really a valid one--is durability negatively correlated with technological sophistication? Likewise, what emphasis should be given to cost control--both with respect to the level of investment in the R&D process and with respect to unit procurement costs and ownership costs? Can marginally higher front-end investments be shown to produce significant economic returns at the production or deployment stages?

These are just a few instance of the basic conceptual problems that now face the managers of major engineering programs. At a more detailed level, the engineering manager is also now required to cope with a broad array of highly specialized support services as integral aspects of the design team concept. The primary example of what is happening is represented by the inclusion of logistics analysis as part of the overall engineering design process. Logistics support encompasses most of the so-called "ilities"--maintainability, reliability, producibility, etc. While the insertion of these supporting specialities into the system development process is intended to help the engineering manager produce a better system, they also constitute a source of distraction--particularly insofar as they involve concepts,

methods, terminologies, and value criteria that fall outside the conventional areas of engineering experience. It is true that the concerns upon which these support services are focused are not in themselves new concerns--they have always been a part of good engineering practices--but in recent times they have become more insular and thus more difficult to integrate into a unified, coherent program effort.

Even more distinctive in the present array of specialized support services is human factors engineering (HFE). The historical pattern of the relationship between military systems engineering and HFE provides a useful perspective on the problem. For all practical purposes, HFE emerged as a support speciality during World War II. In that context, it was manifest that individuals with extensive training in the bio-psychological disciplines could help materially in resolving engineering problems in such matters as operability, habitability, and maintainability.

In the immediate post-war era, "human factors" came to be regarded as an entirely legitimate component of the systems engineering discipline. Indeed, the scope of responsibility assigned to the human factors specialist often included all aspects of manning for the system being developed. The domain then included planning responsibility for recruitment, selection, training, staffing, and the design of the critical human-machine component interfaces.

For reasons that are not entirely clear, this apparently constructive relationship between HFE and systems engineering went into a decline in the 1960s and 1970s. It has only been in the past three to four years that a concerted attempt to repair the relationship has been mounted.

If the reasons for the decline are obscure, the reasons for undertaking a repair effort are not. First, the human resource pool available to the military services is shrinking. There are simply fewer people of recruitable age. Second, those who are recruited are likely to have somewhat lower academic aptitude scores than their predecessors. Third, retention of experienced technicians has not been high. Fourth, equipment now being deployed incorporates very sophisticated technology. Such equipment is sometimes more difficult to operate and it is frequently more difficult to maintain.

In short, a form of mismatch between available human capabilities and the demands placed on such capabilities by modern military systems has been happening. This is the kind of problem that has been--historically--the focal point of human factors engineering. Therefore it seems logical to attempt to repair and revitalize the role of human factors engineering in the military systems development process.

The present project--of which this document is only a part--was one component of a broader effort of repair initiation. Specifically, at its inception, the goal was to find out if there were good ways by which engineering managers could forecast the payoffs from the inclusion of HFE in the development process. It was hypothesized that if engineering managers could be given such a tool, they would use it and come to feel more confident about the investment of some of their budgetary resources in HFE support activities for their programs. If possible, they were to be provided with a methodology that would permit them to compute something like an expected return-on-investment.

As might be guessed, such an ideal forecasting tool was not entirely feasible. However, it was possible to demonstrate that the use of variants of the formal methodology called impact assessment--even some rather crude variants--were both feasible and useful. The basic methodology of impact assessment is described in the project report listed in the Preface. Included in that list is a program manager's guide that incorporates the main thrust of the project reports concisely and in a format that is more appropriate for the engineering manager who is not also a human factors specialist.

The present document takes this venture one step further. The objective is to help the engineering manager become an enlightened consumer. To achieve this objective, we have prepared a set of materials around which a course of instruction can be built. In other words, what is presented here is an annotated syllabus for a course of instruction that might be entitled--"Human Factors Engineering for the Engineering Manager" or "How to Get the Most Out of Your Investment of Program Funds in Human Factors Work." Because it is a syllabus, in effect an instructor's planning aid, the remainder of this document will be addressed to those who have been assigned to carry out the instructor's functions.

Note to the Instructor

As suggested in the General Introduction, the thrust of the program of instruction is toward improving the ability of engineering managers to utilize HFE support services most effectively. It is intended that the syllabus and annotations that make up the main contents of the present document can be used for two purposes: as a planning base for a short course that can stand alone or for a segment or module of a more extensive, more comprehensive course in a program management for system developers.

Emphasis is given to the notion of a planning base. It is _not_ intended that the syllabus and its associated materials become an iron-clad directive on how to teach engineering managers about HFE. There are simply too many variations in instructional setting, composition of the student body, and detailed instructional objectives for any single course configuration to fit all combinations of circumstances. What is provided is an overall organization of subject matter, some key points concerning the relationship of HFE to the military system development process, and some detailed instructional aids in the form of checklists, discussion prompts, class exercise scripts, and suggested sources of supplementary information. In a sense, this is a tool kit and it is the instructor's responsibility to choose the right tools for the particular situation and, if necessary, to add materials from other sources.

The purpose is _not_ to transform systems engineers or engineering managers into do-it-yourself human factors specialists. Educational practice and experience indicates

that the training of even a journeyman human factors specialist is at least a three-year effort. Rather than turning out novice practitioners, the end product should be a sympathetic and informed consumer of human factors services, someone who understands the reasons why the specialty exists, what contributions it can provide to military systems development work, and what its limitations are as well.

The structure of the syllabus is in two parts. The first and main part is composed of three instructional units that relate in succession to the three basic questions: why, what, and how. Each of these units is composed of a series of visual presentations set up for use in an overhead projector or similar device. Each "visual" is accompanied by script-like suggestions for the instructor's oral presentation. These materials can be rearranged or augmented by the instructor to fit the particular situation. The three "modules" are entitled:

1. Enhancing System Cost-Effectiveness with Human Factors Contributions
2. Building the Human Factors Knowledge Base and Applications Procedures
3. Human Factors in the Acquisition Cycle.

The second part is simply a description of a set of student exercises. The intent is to provide a basis for student participation in an active mode that is relevant in the sense of being reasonably realistic and is also commensurate with the student's level of knowledge and experience. Again, the framework is set up so that the instructor can modify or augment the materials based on the circumstances and the available resources.

MODULE 1

ENHANCING SYSTEM COST-EFFECTIVENESS WITH HUMAN FACTORS CONTRIBUTIONS

Note to the Instructor

One of the catch phrases in current use is "forward thinking." It has a positive connotation, but it simply means keeping aware of the future consequences of decisions made in the present. In a real sense, HFE is a concentrated instance of forward thinking. The human factors specialist is (or should be) preoccupied by the question: Given a military mission and one or more conceptual configurations of systems that might carry out that mission, what decisions must be made now that will help ensure that the human complement of the system--operators and maintainers--will be able to fulfill their roles in meeting mission objectives?

As a practical matter, the mode of thinking on the part of the human factors specialist is often defensive in the sense of preventing mistakes in the form of design deficiencies. The categories of possible design deficiencies are legion. Systems have been designed that would need two operators to carry out some segment of the mission when provision is made for only a single operator position. Systems have been designed that require operators to have memorized page after page of arbitrary codes that they must use to control computer functions while under battle stresses. Systems have been designed that require the operator to make himself extremely vulnerable to enemy counterfire. Systems have been designed so that access to components that require frequent replacement is so obstructed that the whole device must be dismantled for minor repairs to be accomplished. Systems have been designed so that the

physiological well-being of the operators is sacrificed in order to protect some fragile equipment components. (Specifically, for example, the B-58 Hustler bomber was designed so that if the main air cooling subsystem failed, the back-up subsystem was used to cool the elaborate avionics while the cramped cockpits were allowed to heat up to the boundary levels of human physiological tolerance).

While it is possible and desirable for the human factors specialist to relate to other members of the system design team in a positive, constructive manner--saying, in effect, what is good design practice from a human factors point-of-view--it is inevitable that some of the contributions from the human factors source will be in the form of prohibitions. In other words, it is often the responsibility of the human factors specialist to tell other members of the design team what they cannot or should not do. Thus some designer's carefully contrived solution to a difficult problem--a solution that might involve the inventive use of some esoteric engineering knowledge--might be greeted by the human factors specialist in a negative way. The engineering solution might be excellent but it could have an unanticipated negative consequence for the human operator or maintainer.

Put bluntly, a portion of the human factors specialist's role in the design team is to act as a critic or censor of certain design proposals. If this role appears to be carried out in an arbitrary manner, powerful incentives will be generated to exclude or constrain the human factors inputs. While some diplomacy and common courtesy can ameliorate the potential for conflict to some degree, the more substantial basis for amelioration is an appreciation on the part of the other members of the design team of the reasons why the critic role must be undertaken and what the composition of the knowledge base for the

position taken by the human factors specialist is. Similarly, the other members of the design team need to be convinced that it is better for the issues to surface and be resolved early in the development sequence rather than coming out at a DSARC hearing, or, worse, becoming the cause of a costly retrofit effort.

One of the related points that must be emphasized is that systems can begin to drift toward configurations that are mismatched to their human complements very early in the design process. During the mission definition and conceptual phases there is a perfectly natural tendency on the part of the design team to focus intensively on the threat factor or the technological opportunity that provided the instigation for the design and development sequence to begin. Consideration of the human operator or maintainer tends to be regarded as marginally relevant in such situations. If considered at all, the human operator is conceived as a fixed parameter. Then configuration decisions are made which slowly but surely become irrevocable. Ultimately, the natural inertia of the system development process leads to the actual fabrication of one or more copies of a system that is not as operable or maintainable as it should be. Such a process of design drift can readily be seen in the development of several recent combat aircraft (e.g., the Harrier II) where reduced cockpit space gradually became a problem because of successive additions of equipment items.

These are some of the reasons why the human factors specialist should be included in the earliest stages of the system development process. If he is not included, he will have to confront extremely difficult design problems in the late stages of the development sequence that could have been

avoided altogether if given earlier attention. The old saying about an ounce of prevention being worth a pound of cure is quite appropriate to the consideration of when and how human factors should be incorporated in the system design process.

The unit that follows is intended to convey these points and others. However, the first subunit has an administrative purpose in the sense that it describes the course structure. The rest of the unit then addresses the question: Why do we need human factors in the military system development process?

MODULE 1

ENHANCING SYSTEM COST-EFFECTIVENESS WITH HUMAN FACTORS CONTRIBUTIONS

COURSE OBJECTIVES

– HELP ORIENT ENGINEERING MANAGERS TOWARD THE ACCEPTANCE AND CONSTRUCTIVE UTILIZATION OF HUMAN FACTORS CONTRIBUTIONS THROUGH –

- UNDERSTANDING THE EXPERIENCE BASE OF HUMAN FACTORS
- UNDERSTANDING THE RESEARCH BASE OF HUMAN FACTORS
- KNOWING WHAT CONTRIBUTIONS TO EXPECT AND DEMAND
- GUIDANCE IN HOW TO ORGANIZE THE HUMAN FACTORS EFFORT
- GUIDANCE IN PREDICTING AND EVALUATING THE QUALITY OF THE CONTRIBUTION

Suggestions for
Instructor Comments #1.1

The engineering manager has a responsibility to invest the funds that are allotted for a system developed program in ways that will result in payoffs in the form of higher levels of performance, more rapid deployment, and lower life-cycle costs. The engineering manager must ask (himself) how much to invest in human factors and when to make that investment. When buying something intangible such as a service, it is a good thing to know something about the knowledge base from which the service is derived. What sorts of facts are crucial and how were they established? It also helps to know what to expect: What form will the service take? How can I know whether I am getting my money's worth? Can I predict in advance how much of a return-on-investment I will receive? This instructional course should help answer these kinds of questions.

COURSE STRUCTURE

- **THREE MODULES**
  - THE PROBLEM: HOW THE HUMAN ELEMENT CAN ENHANCE OR IMPAIR SYSTEM COST-EFFECTIVENESS
  - THE APPROACH: KNOWLEDGE AND TECHNIQUES FROM RESEARCH AND FROM PRACTICAL EXPERIENCE
  - THE OUTCOME: PROCEDURES FOR HUMAN FACTORS PARTICIPATION IN THE SYSTEM ACQUISITION PROCESS

- **STUDENT ACTIVITIES**
  - GROUP PROBLEM SOLVING
  - INDIVIDUAL PLANNING AND DECISIONMAKING

Suggestions for
Instructor Comments #1.2

The main job is to provide everyone (all students) with the same basic conceptual tools. In effect, this course is an introduction to human factors from an engineering manager's point of view. The idea is to help you, the student, look upon human factors as a resource to be managed in much the same way that your other design capabilities are managed. It is recognizing that most prospective engineering managers have had little prior exposure to the knowledge base of human factors. Therefore, human factors as a subject requires a somewhat different, more intensive form of coverage.

(Instructor explains each point on the graphic.)

WHAT IS HUMAN FACTORS?

- THE STUDY OF THE INTERACTION OF HUMANS WITH MECHANICAL, ELECTROMECHANCIAL, AND ELECTRONIC DEVICES
- THE ANALYSIS OF FUNCTIONAL REQUIREMENTS IN SYSTEM DESIGN
- THE APPLICATION OF A SPECIAL SET OF CRITERIA IN THE EVALUATION OF DESIGN ALTERNATIVES

Suggestions for
Instructor Comment #1.3

A comprehensive definition of human factors R&D that is used by DOD and all service does not exist. This is not to suggest that we do not already know essentially what human factors is, but rather to suggest that we are not overly interested in a precise, academic definition of human factors for this course. The three activities mentioned in the graphic provide one useful perspective. First there is a logical progression from study to analysis to application. The analysis activity suggests also the role of representing the user and maintainer in the early stages of the development process. The special criteria to which the last point refers are those that come under the rubric of human-machine compatibility.

A somewhat more formal definition is available from DOD. It comes from the Technology Coordination Paper for FY 78 and reads as follows:

> Human factors technology is concerned with the design, development, evaluation, and deployment of manned systems so that human operators would be able to operate and maintain military systems at their optimum performance level. This includes the systematic investigation of how the design of a person's job and the tools that are provided affect his capacity to do a job.

DOD DEFINITIONS

- **HUMAN FACTORS–**

  DEVELOPMENT OF IMPROVED METHODS AND TECHNOLOGIES FOR THE ANALYSIS, DESIGN, AND EVALUATION OF EQUIPMENT/SYSTEMS FOR SAFER AND MORE EFFICIENT OPERATION AND MAINTENANCE.

- **PERSONNEL AND MANPOWER–**

  DEVELOPMENT OF TECHNIQUES/METHODS FOR UTILIZING AVAILABLE PERSONNEL RESOURCES THROUGH IMPROVED SELECTION, JOB ASSIGNMENT, ORGANIZATIONAL ANALYSIS, AND MANAGEMENT TECHNIQUES TO MEET COMBAT AVAILABLE AND PROJECTED FORCE NEED.

- **EDUCATION AND TRAINING–**

  DEVELOPMENT OF EDUCATIONAL/TRAINING METHODS AND MEDIA FOR MANAGING, DESIGNING, AND EVALUATING NEW GENERATION INSTRUCTIONAL SYSTEMS FOR MILITARY APPLICATIONS.

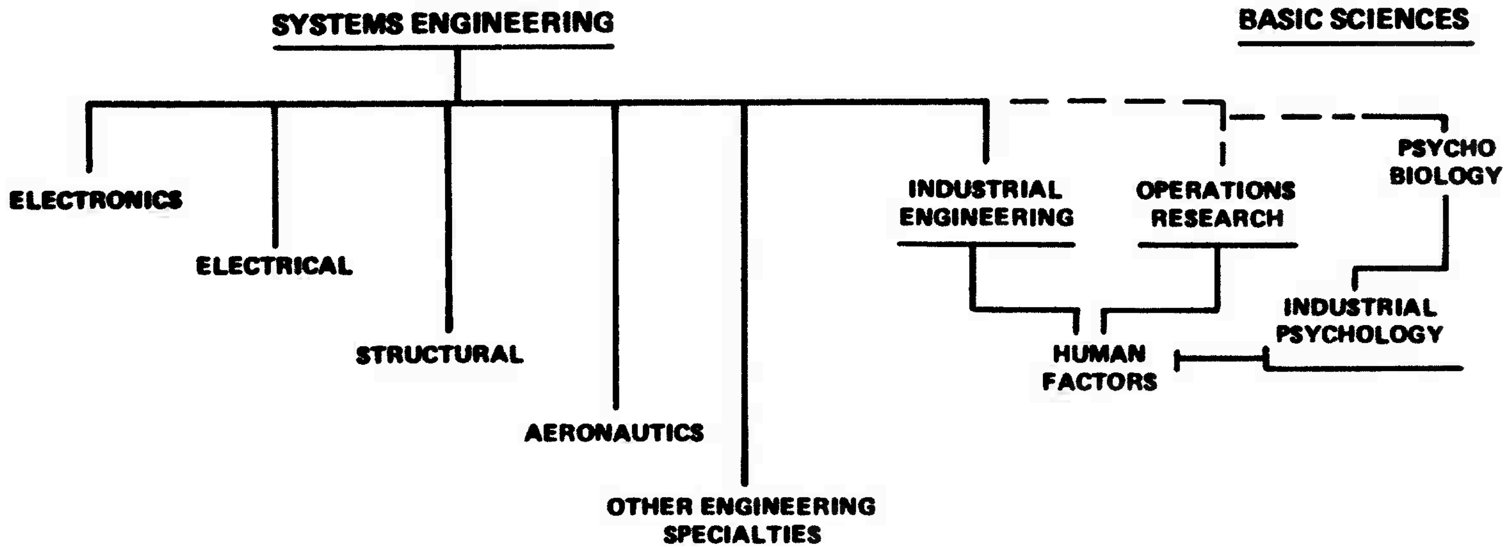
- **SIMULATION AND TRAINING DEVICES–**

  DEVELOPMENT OF COST-EFFECTIVE TRAINING EQUIPMENT AND TECHNOLOGY THAT PRODUCE THE NEEDED PERFORMANCE FOR OPERATION AND MAINTENANCE OF MILITARY SYSTEMS.

SSuggestions for
Instructor Comment #1.4

For the purposes of this course, we also need to know that human factors is one of the four categories of people-related research funded as part of the RDT&E budget of the DOD. These four categories have been defined by the Military Assistant for Training and Personnel Technology in the Office of the Under Secretary of Defense for Research and Engineering in some recent briefing materials. These definitions are provided by the graphic.

THE RELATIONSHIP OF HUMAN FACTORS TO SYSTEMS ENGINEERING



Suggestions for
Instructor Comments #1.5

It is also useful to define human factors engineering by its relationship with the other engineering disciplines. In one sense, systems engineering represents the coming together of several of the main areas of engineering specialization. Systems engineering reintegrates the knowledge and techniques that have been acquired by those in each of the several specialties. Human factors engineering can be regarded simply as another such specialty. However, the linkage can also be seen to be more complicated. Historically, human factors work has often been tied-in with the work of industrial engineers. Collaboration has also been close with operations research. However, the unique aspect is that human factors provides the channel for knowledge from the basic sciences such as physiology and psychobiology to be fed into the systems engineering enterprise. Often, this channel goes by way of industrial psychology as a means of translating basic research findings into terms that are appropriate for practical applications.

(Note: The instructor should attempt to convey the idea of a natural kinship between HFE and systems engineering--a kind of shared parentage.)

THE GENERAL GOALS OF HUMAN FACTORS ENGINEERING ARE THE SAME AS THE GOALS OF MILITARY SYSTEMS ENGINEERING:

IMPROVING THE DESIGN OF SYSTEMS

- MEETING AND DEFEATING THE MILITARY THREAT
- EXPLOITATION OF TECHNOLOGICAL OPPORTUNITIES
- FULFILLING OPERATIONAL CRITERIA
  - READINESS
  - DURABILITY
  - LETHALITY
  - OPERABILITY. . .etc.
- CONTAINING AND CONTROLLING COSTS

Suggestions for
Instructor Comments #1.6

The functional goals of the human factors specialist are the same as the goals of the other members of the system development team (Reiterate the points from the visual presentation verbatim.) The difference is one of focus. The human element is seen as a factor that can either facilitate or impair system performance and that can either inflate or deflate system costs. The direction of the effect is seen to be related to characteristics of the overall configuration or specific design features or both. The job of the human factors specialist is to help ensure that the configuration and that specific design features are incorporated that are compatible with known human characteristics. Because humans differ--one from the other--it is conceivable that a given design feature, for example, might be compatible with some humans but not all. Such a feature might be incorporated in the design for reasons of an overriding engineering advantage, for example, In such instances, the human factors specialist has the responsibility for defining and asserting selection, training, and/or assignment criteria to ensure that only those humans who will, indeed, find the system to be compatible are assigned to operate or maintain it.

TO ACHIEVE OPTIMIZATION OF THE HUMAN-MACHINE INTERFACE–

- DESIGN TO ACCOMMODATE HUMAN CAPABILITIES AND LIMITATIONS DURING ALL STAGES OF THE SYSTEM DEVELOPMENT PROCESS

- FACILITATE ACCOMMODATION BY SUPPORT OF APPROPRIATE RECRUITMENT, SELECTION, TRAINING, AND RETENTION PROGRAMS

Suggestions for
Instructor Comments #1.7

Human factors specialists must not only be "sensitive to" human capabilities and limitations, they must know what human factors are in a factual way and what implications these attributes have for different types of systems and different kinds of design issues. For example, the human ability to detect a target as a visual image on a radar display that is cluttered by electronic noise or ECM can be mapped in a quantitative way. Likewise, the capability of a computer to process such images to decrease clutter and to enhance the target image can also be specified. The design decision can then be cast in terms of rational trade-offs. How much does image enhancement cost? Does it make the system more vulnerable to other forms of ECM? Where is the best balance between investment in image enhancement and reliance on the perceptual capabilities of the human operator? Can we define, select, and assign operators who are so good at target detection that we can economize on computer hardware or software?

THE RELATIONSHIP BETWEEN HUMAN FACTORS ENGINEERING AND MANPOWER, PERSONNEL, AND TRAINING CONSIDERATIONS IS ONE OF MUTUAL FACILITATION

– <u>GOOD HUMAN FACTORS ENGINEERING WORK CAN–</u>

- REDUCE OR HOLD DOWN SYSTEMS MANNING REQUIREMENTS
- MINIMIZE CREW ATTRITION DUE TO ACCIDENTS OR ENEMY ACTIONS
- INCREASE RETENTION BY IMPROVED JOB ENVIRONMENTS AND CONDITIONS OF WORK
- CONTROL THE TRAINING BURDEN BY LIMITING SPECIAL SKILLS REQUIREMENTS

– <u>GOOD MANPOWER, PERSONNEL, AND TRAINING PLANNING AND MANAGEMENT CAN–</u>

- PERMIT BETTER EXPLOITATION OF ADVANCED TECHNOLOGIES
- REDUCE CONSTRAINTS ON DESIGN TRADE-OFFS
- CONTROL DEPLOYMENT AND RETR.OFIT COSTS

Suggestions for
Instructor Comments #1.8

It often appears as if military executives and engineering managers find it easier to think about (conceptualize) manpower, personnel, and training (MPT) considerations than to think about human factors design considerations. In any case, the level of investment of both people and funds is certainly higher with respect to the former. Thus, in some ways, MPT considerations might be regarded as dominant or structured so as to incorporate HFE considerations as a subsidiary area. However, in fact, MPT and HFE are collateral considerations and doing one well can enhance the effectiveness of the other. For example, if a system is designed so that there is a statistically higher probability that the crew will survive hostile counteractions, the flow rate of replacement personnel can be reduced which in turn relieves the strain on recruitment, logistics management, and training facilities. Likewise, if the MPT process can produce sufficient numbers of well-trained people to operate a given system, it could permit the designers to utilize the most advanced--even intensive--technologies.

THE PROBLEM OF THE AMALGAMATION OF HFE INTO MILITARY SYSTEM DEVELOPMENT HAS TWO ASPECTS

- THERE ARE TECHNICAL ASPECTS INVOLVED IN THE CHOICE BETWEEN DESIGN OPTIONS

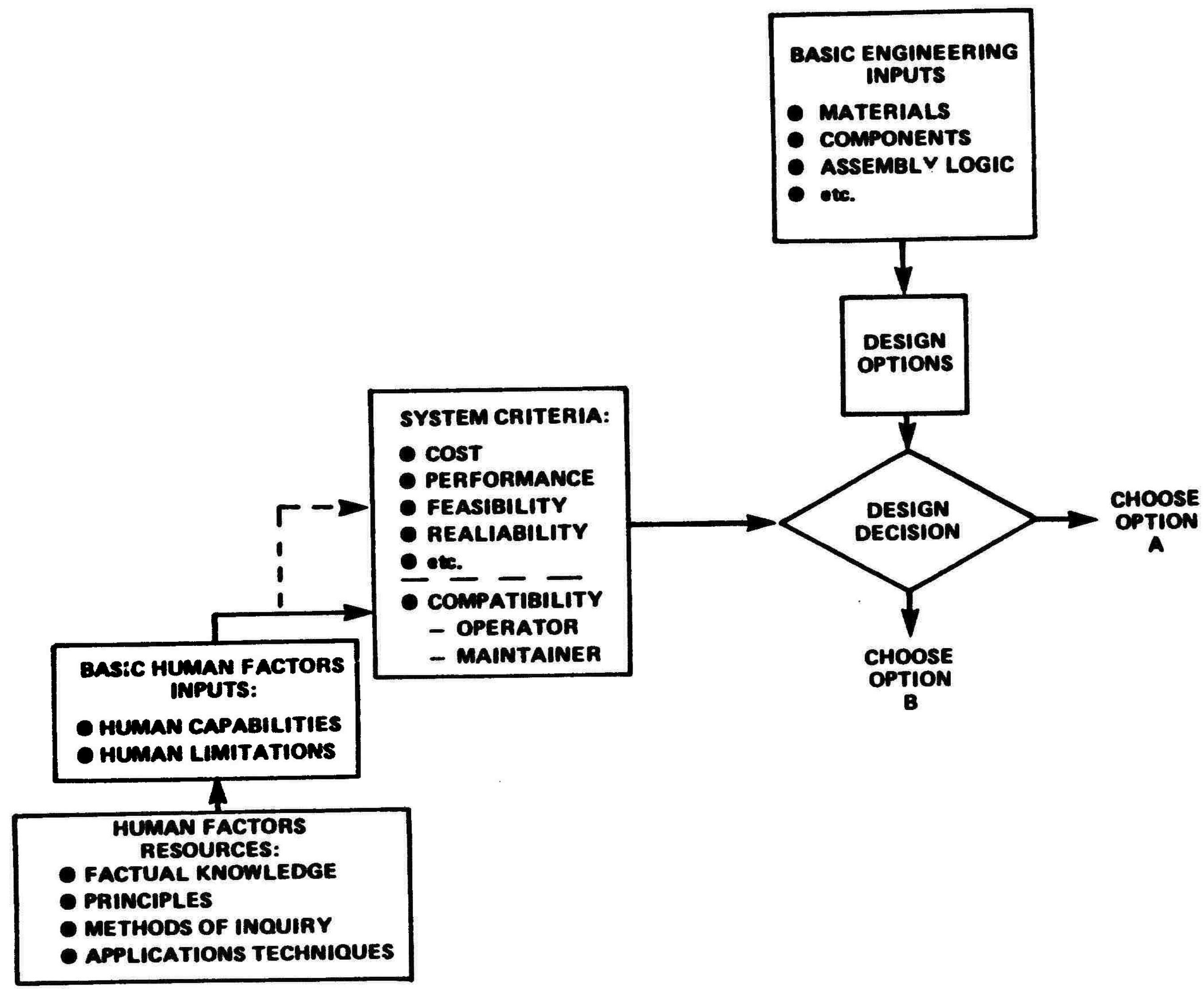
- THERE ARE MANAGEMENT ASPECTS IN ARRANGING FOR THE FLOW OF TECHNICAL INPUTS

Suggestions for
Instructor Comments #1.9

If the virtues of human factors contributions to the development of military systems are so clear and straightforward, why are these contributions not eagerly sought by engineering managers and not eagerly utilized by system designers? There are many answers to this question--each of which provides only a partial explanation. One answer is that the virtues of human factors have not been effectively communicated. Some of the best human factors specialists have been more concerned with the research side of the enterprise so that the applications side has been neglected. Also, there is an anology between seeking human factors contributions and seeking a dental check-up. The virtue of seeing the dentist is obvious in terms of long-range outcomes but the short-range effect can involve some discomfort.

(There are implied negative incentives in that choosing between design options will be made more complicated than it already is and since arranging for the inputs, e.g., establishing the billet within the design team, is a burdensome routine.)

A PROCESS MODEL AT THE LEVEL OF SPECIFIC DESIGN DECISION MAKING



Suggestions for
Instructor Comments #1.10

This graphic shows how the amalgamation can take place at the nuts and bolts level of making specific design decisions. The diagram emphasizes the potential human factors contribution to the evaluation of the design options (which can, of course, number more than two). It shows how the knowledge base is mined to provide inputs that join or supplement other criteria. It also reveals that it is not likely that the human factors contributors will often invent design alternatives. It happens from time to time but it mainly occurs in the setting of training device design. Thus the main function is not to design but to assess in a relative manner the design alternatives of the engineers.

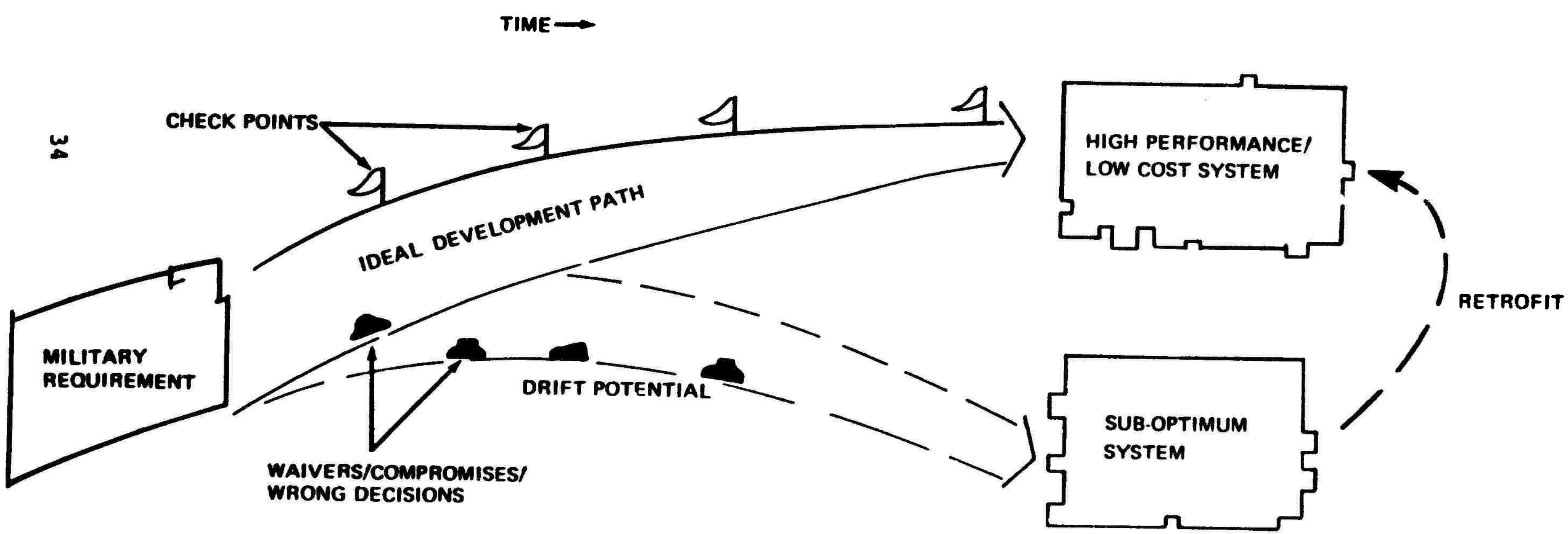
SOME ACTUAL CONSEQUENCES OF AVOIDABLE DESIGN DEFICIENCIES

- A COMPUTERIZED COMMAND POST THAT IS OUT OF ACTION BECAUSE THE ONE OPERATOR THAT KNOWS THE KEYBOARD CODE IS ON SICK CALL
- AN AIRBORNE FIRE CONTROL SYSTEM THAT IS DOWN BECAUSE THE TECHNICAL MANUAL DOES NOT MAKE SENSE TO THE ONLY AVAILABLE MAINTENANCE TECHNICIAN
- THE PARTIALLY DESTROYED AIRCRAFT THAT WAS LANDED WHEELS-UP BECAUSE OF A LACK OF A SAFETY INTERLOCK AND NO WARNING SIGNAL
- THE DEAD INFANTRYMAN WHO MADE A PERFECT TARGET WHILE HOLDING THE LAUNCHER STEADY TO GUIDE THE FLIGHT OF HIS ANTI-TANK MISSILE
- THE RETIRED PILOT WITH MUTILATED FEET WHO EJECTED FROM A COCKPIT THAT WAS TOO SHORT FROM SEAT BACK TO INSTRUMENT PANEL
- THE DESTROYER-ESCORT BEING TOWED TO PORT BECAUSE ACCESS HATCHES TO VITAL ENGINE PARTS WERE OBSTRUCTED BY OTHER EQUIPMENT BOLTED IN PLACE

Suggestions for
Instructor Comments #1.11

What happens if the amalgamation does not take place when it should or to the extent it should? The graphic supplies some end-outcomes taken from actual cases. If these instances are examined carefully, it can be seen that the bad outcome can be traced to choosing the wrong balance of a design tradeoff. For example, in the command post case, funds were spent to train specialist operators rather than to develop software programs and keyboard arrangements that a person with less training could use effectively. It can be true that design choices often reflect a compromise, but some compromises are not properly balanced ones.

SOME OF THE POSSIBLE LONG-RANGE CONSEQUENCES CAN BE SEEN IN A PROCESS OVERVIEW



Suggestions for
Instructor Comments #1.12

A major lesson from relatively recent experience is that it is increasingly difficult to avoid the negative consequences of even minor inadequacies in the final configuration of a military system. Unit costs are high, so much attention is focused on unit performance. The traditional notion that the soldier or sailor will "make do" no longer holds. When soldiers complained early in the Viet Nam conflict that the M-16 rifle was unreliable, a major investigation was launched that ultimately led to a revision in the specifications for the ammunition. All the re-evaluation steps and the subsequent adjustments were very costly. The point is that any kind of post-deployment failure can engender a retrofit action and that even seemingly simple retrofits are disproportionately expensive. In short, prevention is better than a cure. The means for preventing design mistakes are built into the present procurement regulations, but these safeguards are sometimes compromised to the detriment of the whole process.

POSSIBLE COMMON CAUSAL FACTORS BEHIND AVOIDABLE HUMAN FACTORS DESIGN DEFICIENCIES

SOME CONJECTURES

- TECHNOLOGICAL OPPORTUNITY CAN BE GIVEN PRIORITY OVER MILITARY MISSION EFFECTIVENESS
- HIGH TECHNOLOGY = LOW DURABILITY (= INCREASE IN MAINTAINER WORK LOAD)
- THE NEGATIVE SIDE EFFECTS OF DESIGN DECISIONS CAN BE POSTPONED OR HIDDEN
- TOO MUCH RELIANCE IS PUT ON HUMAN CAPACITY TO ADJUST, ADAPT, AND COPE WITH ADVERSE CIRCUMSTANCES
- SHEER NEGLECT OF THE HUMAN OPERATOR OR MAINTAINER'S ACTUAL APTITUDES AND CAPABILITIES

Suggestions for
Instructor Comments #1.13

There is growing literature that has as its main theme the criticism of the administration, planning, and day-to-day management of the system acquisition process. While some of these writings are wrongly motivated or reflect a lack of understanding of the realities of weapon system design, some have been produced by insiders seeking constructive reforms. Some such critics see the tendency to use untried technology in a futile search for the miracle weapon as the culprit. Some critics see designers "gold plating" a system--indulging in esoteric design solutions as a kind of self-indulgent game that leads to high vulnerability and low reliability. Others see the system development process as one that rewards those who can successfully dodge responsibility. Or they see designers avoiding difficult design decisions by simply assuming that the human operator has certain attributes and that these are constant over time and invariant from one operator to another.

THE CONSTRUCTIVE USE OF HUMAN FACTORS CAN BE IMPAIRED BY ORGANIZATIONAL CONSTRAINTS

- INCONSISTENT AND UNRELIABLE BUDGETARY SUPPORT
- FLUCTUATION IN DESIGN OBJECTIVES AND VALUE ASSIGNED TO SPECIFIC DESIGN FEATURES
- FAILURE TO IMPOSE COMPLIANCE WITH PROGRAM DIRECTIVES
- TERRITORIAL UNCERTAINTIES AMONG DESIGN TEAM PARTICIPANTS
- FAILURE TO ENSURE STRICT AND COMPREHENSIVE PROGRAM REVIEW PROCEDURES
- INADEQUATE OPERATIONAL TEST AND EVALUATION PROCEDURES
- ABSENCE OF EFFECTIVE FEEDBACK CHANNELS FROM USERS IN THE FIELD

Suggestions for
Instructor Comments #1.14

The problems listed on the chart are generic and can impair the effective utilization of any and all the specialized contributions to the development process. The real point to be made is that the human factors sources are particularly vulnerable to such constraints. If budgets are unreliable, human factors support may be foregone in order to create a reserve fund to lessen the impact of sudden cut-backs. If human factors and MPT issues are not brought into consideration early in the development process, administrators are confronted with the choice of either delaying the program or waiving a directive. Once the directive is waived, it becomes "unfair" to impose strict test standards. If standards are relaxed during testing and this leads to deployment, negative experiences in the field are more likely to be supressed. Thus if the process gets off to a poor start, it is increasingly difficult to get it back on the track.

THE CONSTRAINTS DISTORT THE BASIC BENIFIT-COST RELATIONSHIP

- IMMEDIATE PAYOFFS RATHER THAN LONG-RUN PAYOFFS ARE SOUGHT
- NEGATIVE OUTCOMES ARE TRANSFERRED—AVOIDABLE DESIGN DEFICIENCIES ARE DISGUISED
- DESIGN DECISIONS ARE MADE UNDER CRASH OR CRISIS CONDITIONS
- AVOIDABLE STRESS SITUATIONS ARE POSTPONED—WITH COST ACCUMULATION A CONSEQUENCE

Suggestions for
Instructor Comments #1.15

Again, the effects of the larger organizational problems can be seen as cumulative. The trigger event is captured well by the phase that apparently originated in the Navy--"Not on my Watch"--which means, of course, that problems are suppressed. When they can be suppressed no longer, they are bigger and the time left to solve them is shorter. Many recent human factors design deficiencies appear to have come about because of this tendency to procrastinate.

BOTH TECHNICAL AND ADMINISTRATIVE PROBLEMS CAN BE MINIMIZED BY EARLY TREATMENT

- ELICITATION OF HIGH-QUALITY HUMAN FACTORS PARTICIPATION EARLY IN THE DEVELOPMENT PROCESS WILL FORESTALL SOME PROBLEMS–
  - BUILD A BASE FOR CONTINUITY
  - ESTABLISH DESIGN CONFIGURATIONS THAT WILL ENHANCE DETAILED DESIGN SOLUTIONS
  - ENCOURAGE TIMELY CONSIDERATION OF MANPOWER IMPLICATIONS AND TRAINING PROVISIONS
  - PROVIDE THE LEAD TIME NEEDED FOR GOOD TECHNICAL DOCUMENTS

- USE OF HUMAN FACTORS AS LINKERS TO END-USERS IN FIELD UNITS CAN BE BENEFICIAL–
  - ADDS TO WEIGHT OF MILITARY MISSION CONSIDERATION IN DESIGN DELIBERATIONS
  - HELPS FACILITATE USER ACCEPTANCE WHEN TESTING AND FINAL DEPLOYMENT TAKES PLACE

Suggestions for
Instructor Comments #1.16

Early treatment, the opposite to procrastination, not only helps prevent later crises but has a constructive effect. For example, even if the goal is to task the prime contractor with the solution of some of the more difficult human factors problems, it helps to have built a conceptual base of understanding on the Government's side so that the full nature of the assignment can be clearly communicated to the prime contractor's technical staff.

Likewise, much later in the development cycle, when end users are likely to be involved in operational tests, any problems stemming from insufficient early human performance considerations will surface. Having had the services of a user advocate in the form of a human factors specialist throughout the development process will then pay significant dividends.

MODULE 2

BUILDING THE HUMAN FACTORS KNOWLEDGE BASE AND APPLICATIONS PROCEDURES

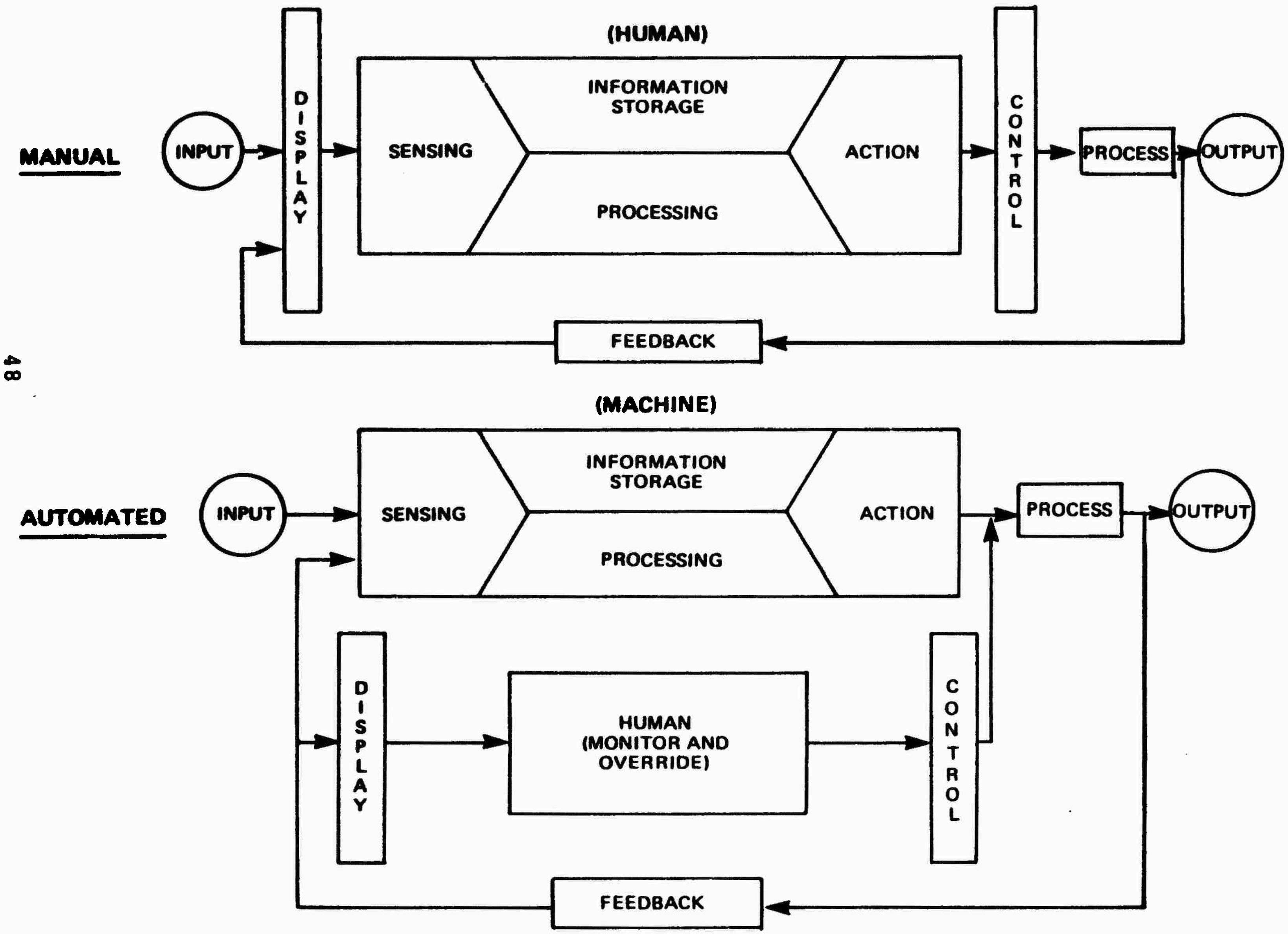
Note to the Instructor

The purpose of this module is to provide students with a deeper understanding of the concepts and methods used in human factors work. The central idea on the conceptual level is the human as an integral part of all systems--including so-called unmanned systems. At the methodological level, there is a sequence of ideas presented. The flow is from research through analysis to applications: the same sequence that was introduced in the preceding module.

MODULE 2

BUILDING THE HUMAN FACTORS KNOWLEDGE BASE AND APPLICATIONS PROCEDURES

CONTROL LOOP STRUCTURES FOR MANUAL AND AUTOMATED SYSTEMS



Suggestions for
Instructor Comments #2.1

The point to be made is that no system works without some kind of human activity driving, or at least monitoring, that system. The expression "man-in-the-loop" has a great deal more significance and meaning than often is acknowledged. A system is incomplete without the individuals who operate and maintain it, and the formal designation of systems personnel is no guarantee that they are functionally integrated into the system. Operators in semiautomatic and automatic systems are required to act on the basis of sensory information and subsequent cognitive information processing and decisionmaking. A systems design which impedes this process essentially leaves man out of the loop.

THE BASIC CAPABILITIES OF PEOPLE AND MACHINES

WHERE HUMANS EXCEL:

- DETECTION OF MASKED SIGNALS
- ACQUISITION OF INCIDENTAL INFORMATION
- MONITORING OF LOW PROBABILITY EVENTS
- UTILIZATION OF INFORMATIONAL REDUNDANCY
- INDUCTIVE DECISION-MAKING
- MAKING OF FINE SENSORY DISCRIMINATIONS

WHERE MACHINES EXCEL:

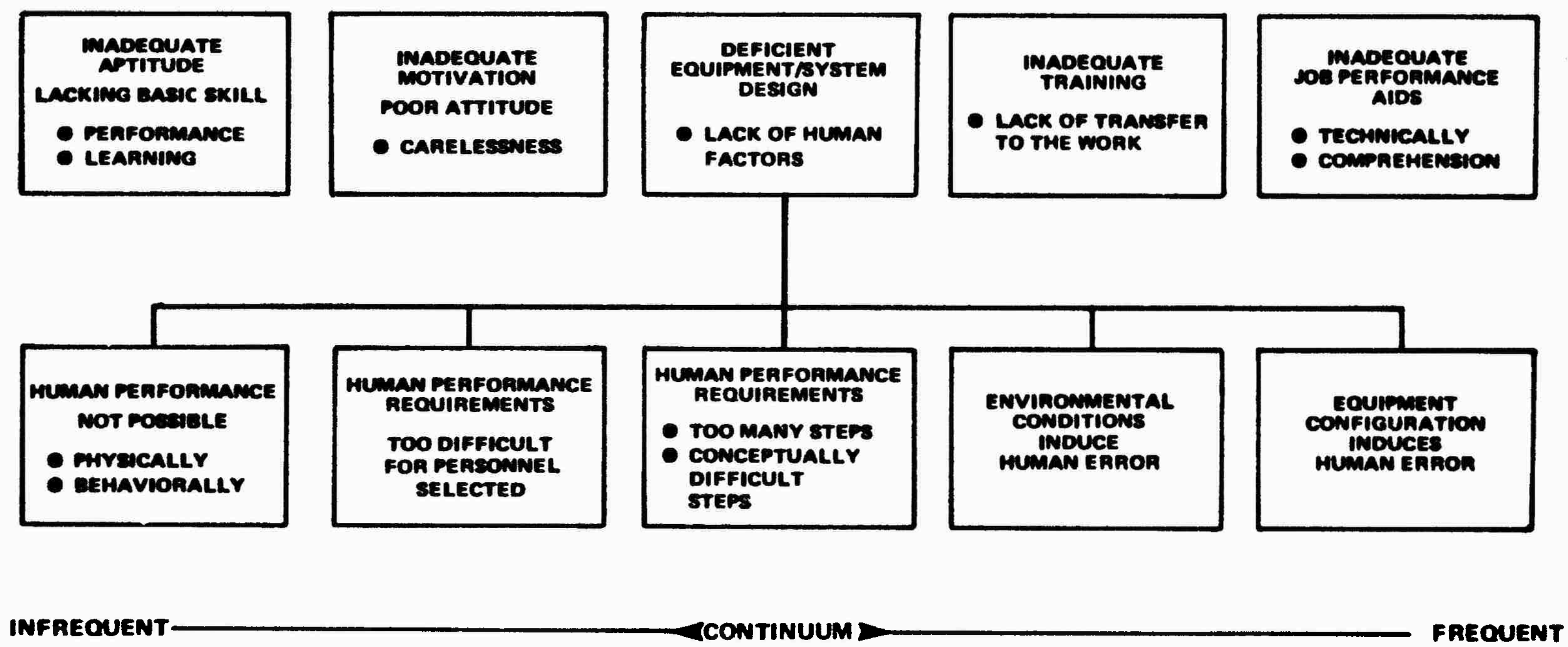
- PROGRAMMABLE FOR HIGH PROBABILITY SITUATIONS
- LARGE CHANNEL CAPACITIES
- EXCELLENT SHORT-TIME MEMORY AND ACCESS TIME
- HIGH RESISTANCE TO PHYSICAL/ENVIRONMENTAL FORCES
- NON-EMOTIONAL

Suggestions for
Instructor Comments #2.2

While it is true that to some extent we can increase the ability of people and select/classify them so that they conform to the requirements imposed by machines, there are basic human capabilities which place severe limitations upon how much we can change or modify people to suit our purposes. At the same time, equipment (automated or non-automated) has limitations as well. And, of course, superimposed upon the situation is the presence of a variety of environmental and situational variables which may or may not be controllable.

The graphic illustrates the capabilities and limitations of people and machines. Although some of the listed characteristics may appear to be a matter of common sense, these categories are based in part on a great deal of experimental research and in themselves constitute important research areas.

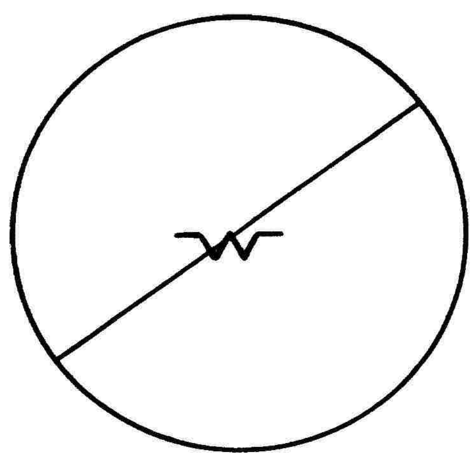
TYPICAL SOURCES OF HUMAN ERROR



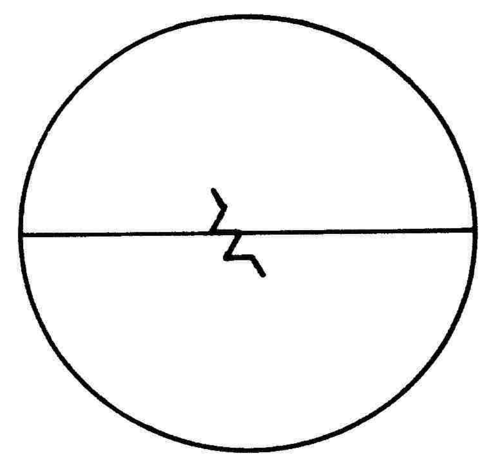
Suggestions for
Instructor Comments #2.3

We can interpret the preceding graphic to be saying that machines are much less variable than people across a wide range of conditions and situations and have outstanding capability for the reception, retention, retrieval, and dissemination of information. For example, information can be keyed into a console at a high rate, stored for great lengths of time, and retrieved upon demand. The equipment involved is not highly subject to fatigue and requires to nourishment or any of the other need-reducing support which human operators do. But this conclusion also leads to a concern about the nature of human variability. In particular, what are the sources of variation in performance? The present graphic summarizes some of what we know. In particular, the focus is given to the matter of deficiencies in equipment design. It also shows that the most frequent problem is that the equipment configuration actually induces human errors. The total picture reveals that there are a number of judgmental mistakes one can make in designing a system. Human abilities can be over- or underestimated, as can those of machines. For example, <u>underestimation</u> of human abilities can produce tasks which are monotonous and overly reliant upon machines. Of course, the more obvious kind of misjudgment is the <u>overestimation</u> of human capability, the result being an overtaxed operator or maintainer. Perhaps the most flagrant mistake made in the design of actual systems is to simply ignore the variability problem altogether. In effect, the designer often uses himself as a model of the end-user and designs the system accordingly. Where this tendency shows up dramatically is in technical documentation. The engineer/designer produces a manual that he or she could use but which is virtually unintelligible to the soldier in the field.

INSIDE–OUT AND OUTSIDE–IN DISPLAYS FOR AIRCRAFT ALTITUDE



INSIDE-OUT (HORIZON BANKS)



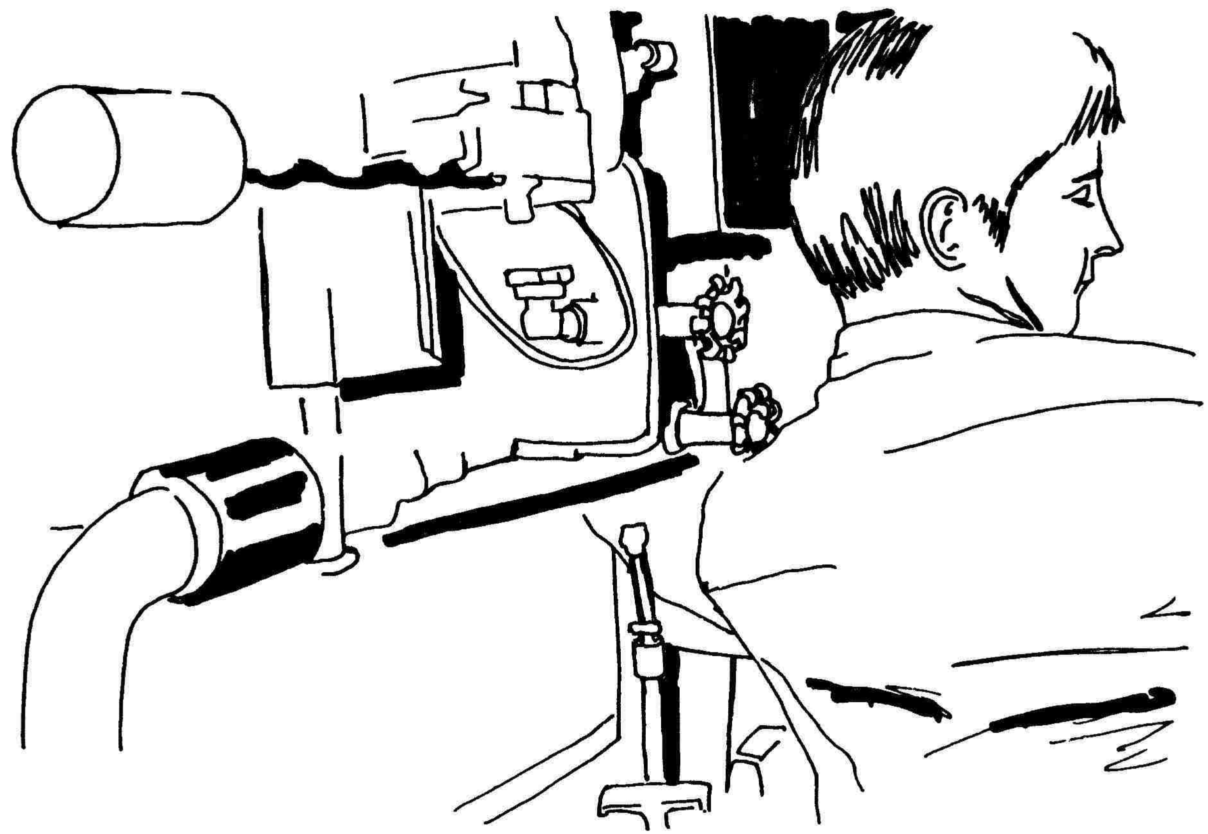
OUTSIDE-IN (AIRCRAFT SYMBOL BANKS)

Suggestions for
Instructor Comment #2.4

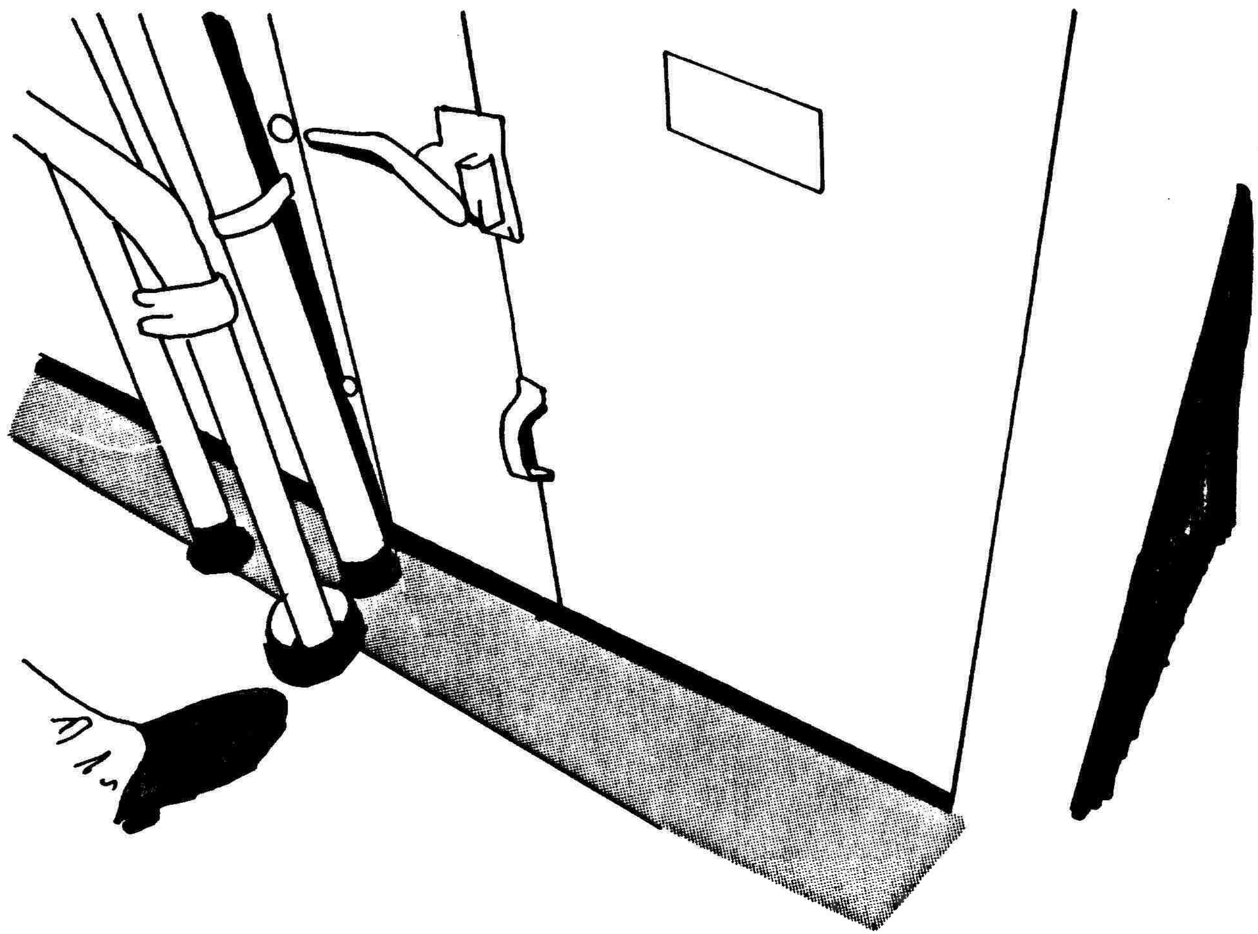
Some of the subtleties in designing equipment to respond to human variability are illustrated in what appears to be a simple problem: How do you display aircraft attitude to a pilot when external visual cues are not available? The obvious answer is to provide an instrument that would mimic what the pilot would see if external visual cues were available. That solution is represented by the inside-out display option. However, a particularly interesting phenomenon was discovered (1951) during pilot training simulation. New pilots often made reversal errors; it was difficult for new pilots to adjust to a moving horizon, and thus the "outside-in" display is sometimes recommended as an alternative.

Numerous other human factors problems are emerging. For example, user acceptance of new technology is a real challenge. In the early dawn of the F-111, the reluctance of pilots to rely on the automatic terrain-following system was the apparent cause of a number of crashes. The capabilities of modern aircraft present very difficult problems in respect to life support (e.g., ejection), habitability (e.g., cockpit space), and systems operation and maintenance. With more compact planes flying faster, at higher altitudes, and with less cockpit space, how do you design them so that pilots can navigate efficiently and simultaneously engage the enemy? The dilemma is that our increasing capability increases the difficulty of matching people to systems equipment.

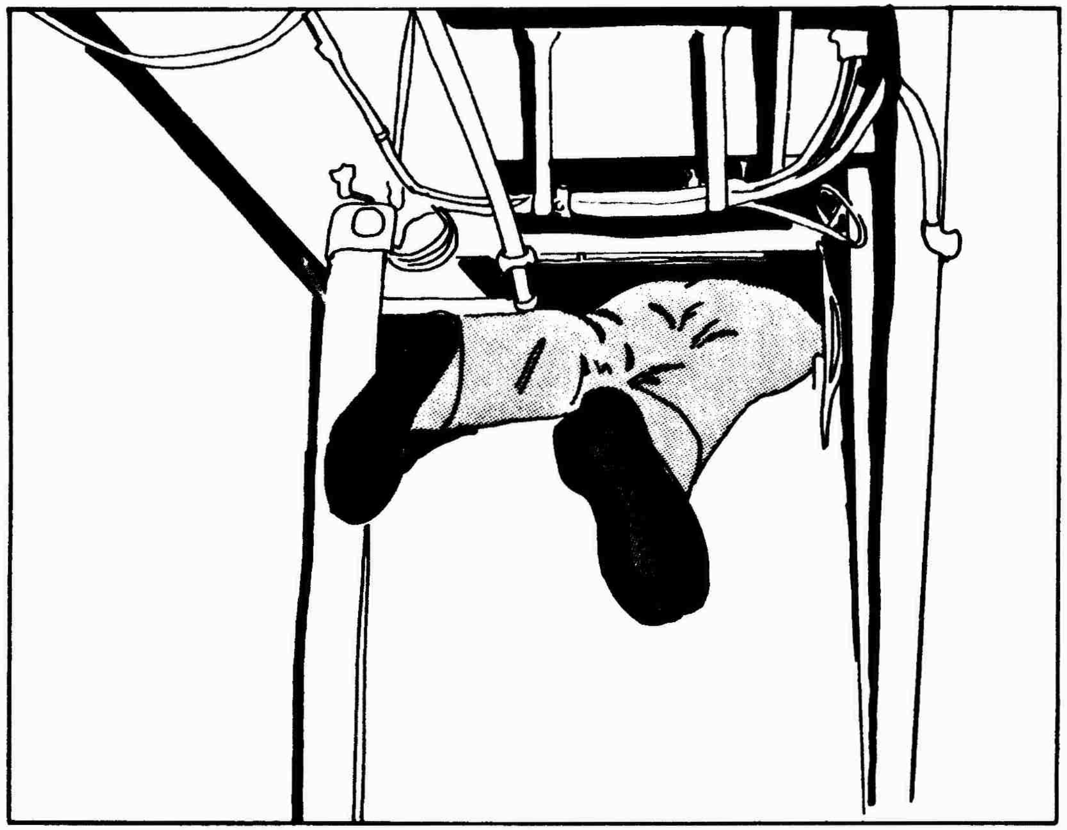
INACCESSIBLE FILTERS ON THE SPS-40B SURFACE SEARCH RADAR



BLOCKED TURBINE ACCESS HATCH ON A DD-963 CLASS SHIP



POOR DUCT MAINTENANCE ACCESSIBILITY ON A DD-963 CLASS SHIP



Suggestions for
Instructor Comments #2.5a, b, & c

A still different perspective on the nature of the designers problems is illustrated by graphics 2.5 a, b, and c. Here we see a set of situations where maintenance personnel are physically restricted from access to parts that must be repaired. The setting is a naval surface ship. While the consequence is almost ludicrous and one is tempted to say something about the native intelligence of ship designers, the real problem is one of priorities. Destroyers are inherently cramped for space--something must be sacrificed--and by sacrificing accessibility, the designers were able to get equipment installed that otherwise would not fit at all.

(In these situations, human variably in extreme form might be an asset in the sense that what the Navy needs is a maintenance staff composed of contortionists.)

REPRESENTATIVE DATA DOMAINS IN BASIC HFE RESEARCH

<u>PHYSIOLOGICAL</u>

- BODILY STRENGTH
- ENDURANCE
- SENSITIVITY TO STRESSORS
  - MECHANICAL (NOISE, VIBRATION)
  - CHEMICAL
  - BIOLOGICAL
- BODILY DIMENSIONS (ANTHROPOMETRY)

<u>PSYCHOLOGICAL</u>

- MEMORY SPAN
- LEARNING RATE
- SENSORY DISCRIMINATION (VISUAL ACUITY)
- REACTION TIME

<u>SOCIAL</u>

- LEADERSHIP
- SOCIAL NEEDS AND VALUES
- COMMUNICATION SKILLS
- ATTITUDES

Suggestions for
Instructor Comments #2.6

Having looked at some notorious problems, it is seemly to turn now to consider some solutions. A useful first question is: Where does the knowledge come from with which solutions can be formulated? One answer is basic research. Such research is done in Government laboratories, universities, and by private contractors. As we have seen, the disciplinary framework can be biology, psychology, or one or more of the other social sciences. Ideally, the results are in the form of generic statements about human capabilities and limitations that are presented as distribution functions that reveal the individual differences aspect or link variations in performance to other, easily discernible attributes. An elementary example would be the strength-of-grip of the human hand. Obviously, some individuals are stronger than others and the characteristics will be related to such attributes as age, weight, and gender. The area of ultimate application of such basic data will be the design of manual controls. A sampling of data domains is provided in the graphic. Most of these domains have been well-explored by now.

GENERAL APPLIED RESEARCH AREAS

- MEASUREMENT
  - PERFORMANCE CRITERIA—MOEs (MEASURES OF EFFECTIVENESS)
  - SAMPLING
  - INSTRUMENTATION—TEST CONSTRUCTION
  - SCALING
- MODELING
  - DECISION ANALYSIS
  - FORECASTING
  - PROCESS SIMULATION
- STATISTICAL TOOL DEVELOPMENT (NON-PARAMETRIC FORMULAE)

Suggestions for
Instructor Comments #2.7

There is another layer of knowledge base development that is less easy to describe. The phrase that is descriptive but somewhat ambiguous is "general applied research." One connotation is that while the research is aimed at a practical objective, it has no specific organizational or system referent. A good example is research on scaling or on some aspect of tests and measurement. The statistical modeling of decisionmaking is another example. The examples reveal that a common feature of this research is an attempt to improve a method or procedure. In military systems development, the relevance of this type of research is for helping to solve problems in selection, training, and manpower forecasting. The results--if they are in the form of methodological advances--can also contribute to the planning of operational tests.

KNOWLEDGE BASE DEVELOPMENT -- NON-SYSTEM-SPECIFIC RESEARCH IN C^3I

SOME RESULTS

- RECOMMENDED OPTIMUM ABBREVIATIONS OF MILITARY TERMS—REDUCED WORK LOAD AND ERRORS
- CONFIGURATION OF INPUT DEVICE (KEYBOARD)
- EVALUATION OF COST-EFFECTIVENESS OF DISPLAY OPTIONS (e.g., GRAPHICS)
- DATA PRIORITIZATION—COMPUTER MEMORY ALLOCATION
- DATA COMPRESSION AND PURGING ROUTINES
- UTILITY OF EMBEDDED TRAINING

Suggestions for
Instructor Comments #2.8

The next form of knowledge base development is also somewhat peculiar. It is systems oriented--even weapon systems oriented but not linked to the development of a particular system. It is, more often than not, linked to a class of systems. The graphic employs C^3I-type systems as a case in point.

The collection of data in this sort of research is usually based on one or another form of model. It can be an abstract mathematical model or a simple flow diagram, but the most convincing results are obtained if the form of the model is real-time simulation. Simulation--as in some so-called dynamic mock-ups--provides a good balance between realistic and experimental control of extraneous variables. The results listed were obtained from studies done in such a controlled laboratory environment and, you will see, each result could have a direct impact on a design or system development decision made by the engineering management team.

THE CLASSIFICATION SYSTEM FOR HUMAN FACTORS R&D

(Taken from the TCP for FY 1979, see Erickson, Miles, & Secrist, 1978)

AREAS	EXAMPLES
HUMAN RELATED	PHYSICAL CHARACTERISTICS
	SENSORY CAPABILITIES
	INFORMATION PROCESSING
	FORECASTING JOB REQUIREMENTS
	MEASURES OF EFFECTIVENESS
HUMAN-MACHINE RELATED (SUBYSTEM ORIENTED)	FLIGHT INSTRUMENTATION
	EQUIPMENT LAYOUT
	MAINTENANCE
	WORKLOAD ASSESSMENT
HUMAN-MACHINE MISSION RELATED	STRATEGIC OFFENSE AND DEFENSE COMMAND AND CONTROL
	TACTICAL OFFENSE AND DEFENSE COMMAND AND CONTROL
	COMMAND AND CONTROL
	MEASURES OF SYSTEM EFFECTIVENESS WITH INPUTS

Suggestions for
Instructor Comments #2.9

System-specific studies are relatively easy to explain and justify. Ideally, such studies feed directly into a difficult engineering choice: Should this attack helicopter be designed with the two crew members side-by-side or in tandem? Which arrangement yields the better net operator performance from both the pilot and the weapons control officer? The study procedure can be closely akin to an operational test or be a simple procedural walk-through as an augmentation of expert opinion. In practice, system-specific studies are <u>not</u> very good sources of data for the development of the knowledge base because the data are too soft and unreliable. In fact, most system-specific studies are not very rigorous because rigor takes too much time. Expertise is the more dominant force in the actual decisionmaking. But that is exactly why the long research "tail" is needed. Data from that "tail" of basic, general applied, and non-system specific research is what makes the difference between an ordinary guess and true expert opinion. The graphic shows how this grey area between rigorous research and the informal guess has been organized to begin to fit the system development process. Remember, it is a framework that is the first step toward the organization of the human factors contribution to a particular system development effort.

AREAS OF OPPORTUNITY FOR HUMAN FACTORS R&D IN THE TECHNOLOGY BASE TO CONTRIBUTE TO MILITARY SYSTEM DEVELOPMENT

SYSTEM DEVELOPMENT PHASE AND (↓) HUMAN FACTORS R&D PRODUCTS	CLASSIFICATION OF HUMAN FACTORS EFFORTS		
	HUMAN RELATED	HUMAN-EQUIPMENT RELATED	HUMAN-EQUIPMENT-MISSION RELATED
MISSION ANALYSIS ↓ THE ROLE OF MAN	1	2	3
CONCEPT DEVELOPMENT ↓ MANNED FUNCTIONS	4	5	6
SYSTEMS DEMONSTRATION/VALIDATION ↓ TASK ANALYSIS & HUMAN ENGINEERING REQUIREMENTS	7	8	9
FULL-SCALE DEVELOPMENT ↓ MAN-MACHINE INTERFACE DESIGN	10	11	12

Suggestions for
Instructor Comments #2.10

We can see how the preceding framework ties into the formal structure of the system development process in this next graphic. The title "areas of opportunity" is apt. Not all systems will draw equally from all the numbered cells in the matrix. However, the relevance of the matrix as a whole can be demonstrated by a deeper look at what happens cell-by-cell. For example, we can ask the question: What kinds of studies or analyses would be done that would fit into cell #5--the intersection of Human-Equipment concerns and Concept Development concerns? A good example comes from studies done on a prototype main battle tank. The study focused on habitability and crew safety. The study confirmed with precise data the effects on the crew compartment of the "heat sink" properties of the tank. That is, the internal temperature and humidity changes lag the external environment by three hours. These data could be fed into the specifications for the internal environmental control system.

In addition, opinion data were also obtained from crewmen concerning the adequacy of escape and evacuation systems and potential design changes. One conclusion was that if a tank were hit, the gunner will be the most vulnerable and would have the greatest difficulty escaping. Also revealed was that lifting straps should be added to uniforms for evacuation of wounded, and that escape/evacuation training was extremely limited and should be augmented.

BASIC STEPS IN AN ALLOCATION OF FUNCTIONS

- SPECIFY THE HUMAN FACTORS CRITERIA SELECTED FOR FUNCTIONS (e.g., RESPONSE TIME, ERROR RATE, COST, SAFETY, etc.).
- LIST THE LIMITATION AND CAPABILITIES OF MAN AND MACHINE
- LIST ALTERNATIVE ALLOCATIONS OF EACH FUNCTION TO:
  ONE OR MORE OPERATORS/MAINTAINERS; MACHINE ONLY; COMBINATION OF MAN/MACHINE
- ESTIMATE FEASIBILITY FOR ALTERNATIVE ALLOCATIONS OF EACH FUNCTION, CONSIDERING THE FOLLOWING:
  - HUMAN PERFORMANCE CAPABILITIES REQUIRED
  - MACHINE CAPABILITIES REQUIRED
  - WORKLOAD
  - USER ACCEPTANCE
  - BOTTLENECKS
  - CRITICALITY OF FUNCTIONS
- EVALUATE THE ALTERNATIVE ALLOCATIONS OF EACH FUNCTION. ALL ALLOCATIONS OF FUNCTIONS SHOULD BE SYSTEMATICALLY COMPARED WITH THE CRITERIA FORMULATED IN THE FIRST STEP.

Suggestions for
Instructor Comments #2.11

We will return to the specific linkages between the human factors effort and the military system development process in the next session. For the present, we need to focus on some of the basic analytic techniques that have been created by human factors specialists as their means of making a unique contribution. One such technique is the analysis of functions for allocation to human and machines. Since functions are the broadly defined activities that combine to achieve the mission goals, it is crucial that early in the development cycle the functions be defined and their sequence and overlap be determined. Also, the "division of labor" between people and machines for each function should be determined. The latter is attained through functions allocation. This is extremely important and quite difficult in that it is the decision methodology for determining the man-machine match for each function. The basic question asked is: Should the function be performed by a person(s), a machine, or some combination of both; if both, how much of each? Since the performance of the system is the product of the performance of the individual functions, the most efficient allocation for each function is extremely important. The basic steps taken in performing such an analysis are shown in the graphic. Essentially, functional criteria must be developed, and then alternative allocations for the function must be compared with the relative capabilities of people and machines and the operational criteria to determine the feasibility of the alternative allocations.

EXAMPLE OF FUNCTION ALLOCATION ANALYSIS & SCREENING WORKSHEET

HYPOTHETICAL TRACKING FUNCTIONS	INHERENT CPERATOR CAPABILITIES					INHERENT EQUIPMENT CAPABILITIES			TOTAL	SCORE	PROPOSED ALLOCATION			
													MACHINE	
	DETECTING SIGNALS IN THE PRESENCE OF HIGH-NOISE ENVIRONMENT (X5)	RECOGNIZING OBJECTS UNDER VARYING CONOITIONS OF PERCEPTION (X4)	HANOLING UNEXPECTEO OCCURRENCES OR LOW-PROBABILITY EVENTS (X4)	REASONING INOUCTIVELY (X1)	PROFITING FROM EXPERIENCE (X2)	RESPONOING OUICKLY TO SIGNALS (X3)	PERFORMING PRECISE ROUTINE REPETITIVE OPERATIONS (X2)	COMPUTING ANO HANDLING LARGE AMOUNTS OF STOREO INFORMATION OUICKLY AND ACCURATELY (X4)	OPERATOR	MACHINE	OPERATOR	BOTH	EQUIPMENT	SOFTWARE
1. DETERMINE IF TARGET TRACKS IN SYSTEM	25	8	12	3	6	9	8	4	81	41	X			
2. ACUTE SEQUENCE	5	4	4	1	2	3	2	4	20	24		X		
3. PUT NEXT TARGET IN TRACK LIST UNDER CLOSE CONTROL	5	4	4	1	2	9	10	4	21	43			X	X
4. ADVANCE HOOK ON DISPLAY TO TRACK COORDINATES	5	4	4	1	4	9	10	4	21	43			X	X
5. DETERMINE IF TARGET VIDEO PRESENT	20	8	8	3	4	9	8	4	70	39	X			
6. DETERMINE IF HOOK LINES UP WITH PRESENT TARGET POSITION, etc.	20	8	8	3	6		8	4	73	40	X			

Suggestions for
Instructor Comments #2.12

This graphic illustrates a matrix used to achieve tentative man-machine allocations for some hypothetical tracking functions. Human and machine capabilities are matched against system functions, the respective capabilities being ranked or rated for each function. Total scores are computed for both human and machine capabilities (by function), and either man or machine, or a combination of the two, is selected as the proposed allocation on the basis of whatever convention has been adopted for evaluating the scores.

Certain evaluative processes are not represented in this example. Such criteria as costs and safety are not shown; these may have been considered in an earlier analysis or were to be part of a later trade-off analysis. Other functional criteria are (we would hope) built into the capabilities listing (e.g., response time).

A PAGE FROM A FUNCTIONS ALLOCATION REPORT

<u>ACTIVATE AND CHECK OPERATION OF AIRCRAFT SYSTEMS</u>

6. PERFORM BUILT-IN TEST (BIT)

<u>ALLOCATION:</u>

AUTOMATED

<u>RATIONALE:</u>

BIT WOULD ENABLE THE PILOT TO MORE FULLY ASSESS THE OPERATIONAL READINESS OF HIS AIRCRAFT. THE GREAT NUMBER OF TESTS WHICH CAN BE MADE REQUIRE A HIGH DEGREE OF AUTOMATION.

ACTIVATE AND CHECK OPERATION OF AIRCRAFT SYSTEMS

7. ACTIVATE AND CHECK OPERATION OF RADAR

<u>ALLOCATION:</u>

PILOT

<u>RATIONALE:</u>

AUTOMATION WOULD NOT ENHANCE RADAR INITIATION AND TERMINATION, THEREFORE, THIS SUBFUNCTION IS MANUAL. THE ADVANTAGE OF THE AUTOMATIC BIT IN CHECKING SYSTEMS OPERATION IS OBVIOUS IN TERMS OF EFFECTIVENESS AND REDUCTION IN OPERATING COMPLEXITY.

ACTIVATE AND CHECK OPERATION OF AIRCRAFT SYSTEMS

8. ACTIVATE AND CHECK COCKPIT CRT DISPLAYS

<u>ALLOCATION:</u>

PILOT

<u>RATIONALE:</u>

ONLY THE PILOT CAN BE FULLY AWARE OF THE OPTIMUM TIME FOR TURN-ON AND CHECKING DISPLAYS FOR ALL OPERATIONAL SITUATIONS.

Suggestions for
Instructor Comments #2.13

The matrix presented in the preceding graphic does not consitute the final product of functions allocation analysis. A page from an actual human factors report showing the descriptive nature of such a product is shown here. The function, rationale, and allocation are briefly summarized, and the more pertinent criteria are mentioned under "Rationale."

AN EXAMPLE OF A TASK ANALYSIS FORM

FUNCTION: (1)	OPERATE AIRCRAFT POWER PLANT AND SYSTEM CONTROLS
TASK: (2)	CONTROL JET ENGINE OPERATION

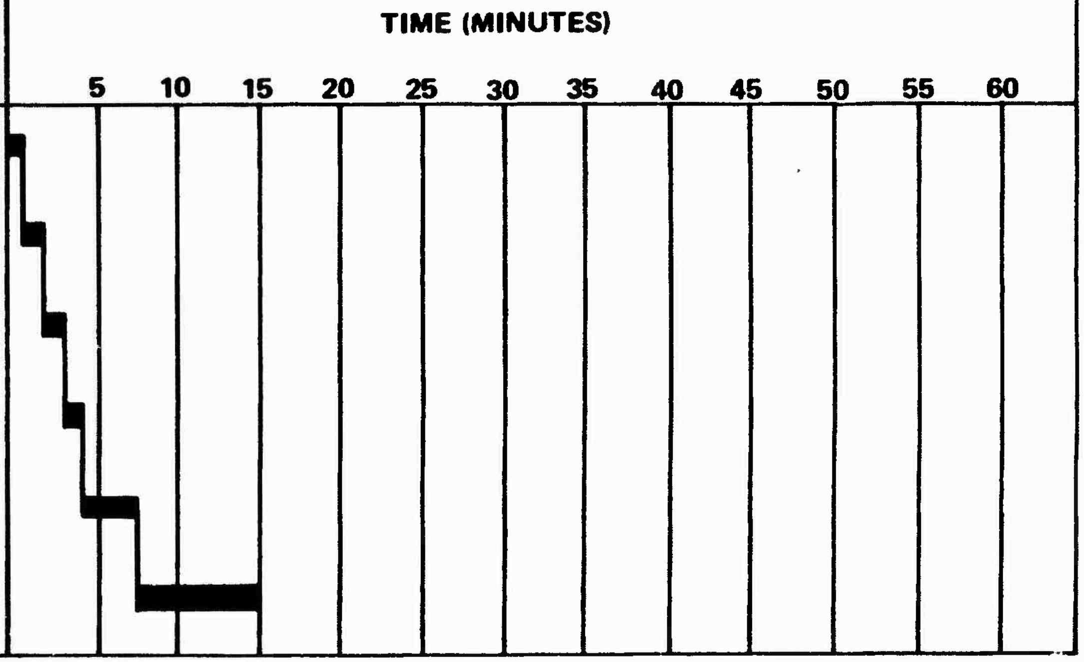
SUBTASK (3)	ACTION STIMULUS (4)	REQUIRED ACTION (5)	FEEDBACK (6)	TASK CLASSIFICATION (7)	POTENTIAL ERRORS (8)	TIME (9)		WORK STATION (10)	SKILL LEVEL (11)
						ALLOWABLE (9a)	NECESSARY (9b)		
3.1 ADJUST ENGINE r.p.m.	4.1 ENGINE r.p.m. ON TACHOMETER	5.1 DEPRESS THROTTLE CONTROL DOWNWARD	6.1 INCREASE IN INDICATED TACHOMETER r.p.m.	7.1 OPERATOR TASK, AIRCRAFT COMMANDER	8.1 a. MISREAD TACHOMETER b. FAIL TO ADJUST THROTTLE TO PROPER r.p.m.	9a.1 10 SEC.	9b.1 7 SEC.	10.1 AIRCRAFT COMMANDER'S SEAT	11.1 LOW

Suggestions for
Instructor Comments #2.14

Once functions allocations have been made, an even more basic analytic technique can come into play--namely, task analysis. Task and subtasks are in essence a combination of elements related by time and purpose, and task analysis is necessary in order to properly structure the man-machine interaction, the product being the system interface requirements. The important elements in a task analysis may be conceptualized in terms of stimulus-organism-response (S-O-R). The stimuli include everything directly influencing the operator, such as the equipment, information flow, and environmental conditions. The organism is the operator and carries with himself/herself a number of states and dynamic characteristics such as skill level, physical condition, body dimensions, etc. Finally, the response includes both purposeful and unintended (error) behavior. The S-O-R variables are embodied in a task analysis and represented in a format such as that shown in the graphic.

EXAMPLE OF A TIME-LINE ANALYSIS (GROSS LEVELS)

TIME LINE SHEET	FUNCTION 10.0 REACT TO THREATS	LOCATION:
FUNCTION REF.	**FUNCTION/TASKS**	**TIME (MINUTES)**
10.1	INITIATE SEARCH	
10.2	DETECT THREATS	
10.3	LOCATE THREATS	
10.4	IDENTIFY THREATS	
10.5	TRACK THREATS	
10.6	ATTACK TREATS	



Suggestions for
Instructor Comments #2.15

A supplementary technique is shown in this graphic. When a number of individual tasks are run against a timeline, it is possible to evaluate workload, derive a basis for needed skill levels, and pinpoint conflicting demands and bottlenecks. Also, such data can provide a foundation for various workspace and interface analyses (such as link analysis).

EXAMPLE:
PERSONNEL REQUIREMENTS DOCUMENTATION

PERSONNEL REQUIREMENTS INFORMATION

JOB CATEGORY: ______________________ DUTY: ________________

OPERATION: ______________________ TASK: ________________

DATE:

TASK ANALYSIS INFORMATION

TASK PERFORMANCE FREQUENCY: ____________ PERFORMANCE TIME: ________

TASK REQUIREMENTS:

PERCEPTUAL LEVEL: ______________________________

DECISION LEVEL: ______________________________

STRESS CONDITIONS: ______________________________

MOTOR SKILLS: ______________________________

PHYSICAL REQUIREMENTS: ______________________________

HEIGHT: ______ STRENGTH: ______ WEIGHT: ______ OTHER: ________

RECOMMENDED CHANGES IN TASK STRUCTURE AND HUMAN REQUIREMENTS: ________

____

PERSONNEL USED IN TASK VERIFICATION: ______________________

COMPANY PROCEDURES KNOWLEDGE TASK REQUIREMENTS: ______________

RECOMMENDED PERSONNEL SELECTION REQUIREMENTS: ______________

GENERAL APTITUDES: ______________________________

GENERAL TRAINING/EDUCATION: ______________________________

RECOMMENDED PRE-SELECTION TESTING:

PERFORMANCE: ______________________________

INTELLIGENCE: ______________________________

INTERESTS: ______________________________

PERSONALITY: ______________________________

SPECIAL: ______________________________

SCOREABLE CHECKLIST PERFORMANCE: ______________________

IN-PLANT TRAINING RECOMMENDATIONS:

REQUIRES NO TRAINING: ______________________________

REQUIRES FAMILIARIZATION: ______________________________

REQUIRES SPECIAL TRAINING: ______________________________

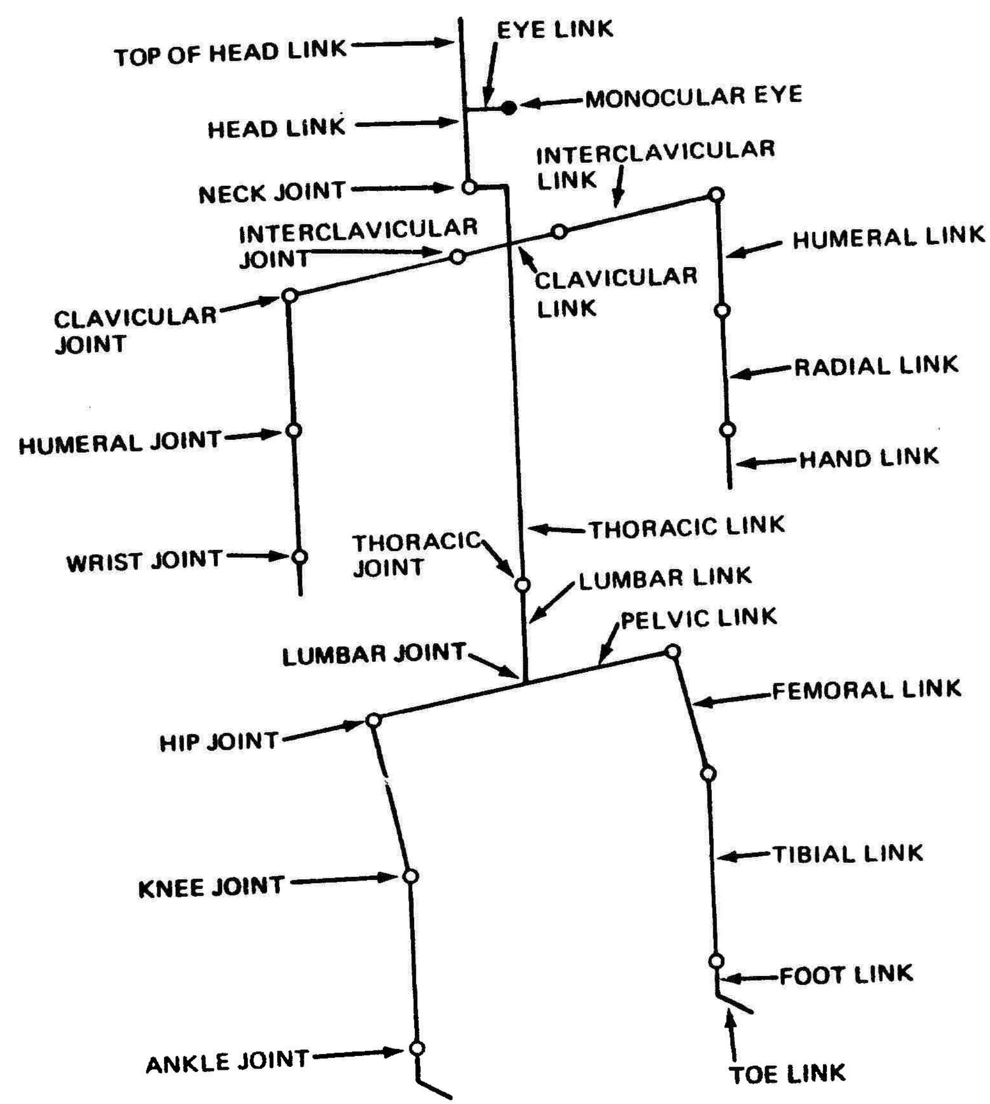
ACTION TAKEN BY PERSONNEL DEPARTMENT:

DATE REPORT FORWARDED: ____________ DATE REPORT RETURNED: ____________

Suggestions for
Instructor Comments #2.16

One of the outcome products of the task analysis work is illustrated by the record form presented here. The form provides the means to relate task analysis findings to the MPT areas of selection and training. In effect, personnel requirements are tentatively <u>inferred</u> from the task analytic findings. The form was taken from a civilian application situation but it is easy to translate into military terms.

C–A–R BODY MODEL



(NOT TO SCALE)

Suggestions for
Instructor Comments #2.17

There are many other analytic procedures more or less unique to human factors work that can help achieve the objective of optimizing the match between human and machine. For example, simulation and modeling techniques have played a major role in past achievements of human factors workers. A good example of the application of modeling--and one that is specific to human factors work--is the Crewstation Assessment of Reach (CAR) model mentioned in the Handbook. The model fundamentally integrates projected cockpit dimensions and related data to predict the percentage of the pilot population the cockpit will be able to accommodate.

MODULE 3

HUMAN FACTORS IN THE ACQUISITION CYCLE

Notes to the Instructor

The acquisition cycle embodies a logic intended to assure that the development of a military system will involve thorough preliminary analysis, systematic planning, and built-in checks and balances. The human factors engineering effort is part of this process, and systems engineers and project managers should be aware of the interrelationship between human factors and the cycle. The major goal of this module is to produce such an understanding in order that the importance of good human factors management will be fully appreciated.

Objectives

Students should have an increased awareness of:

- The formal basis for human factors engineering in systems development.
- The importance of a well-run and concerted human factors effort.
- The eventual payoff of a good human factors effort.

Major Points

- There is a well-documented, official basis for human factors in systems acquisition.
- Good management of the human factors process is of great importance, and poor management can lead to failure.

- Human factors has a tangible payoff in terms of cost-benefits.

The present and final module (3) is completed by reasserting the human factors specialist's role as a representative of the user (operator/maintainer) and summarizing the HFE specialist's qualifications for fulfilling that role.

MODULE 3

HUMAN FACTORS IN THE ACQUISITION CYCLE

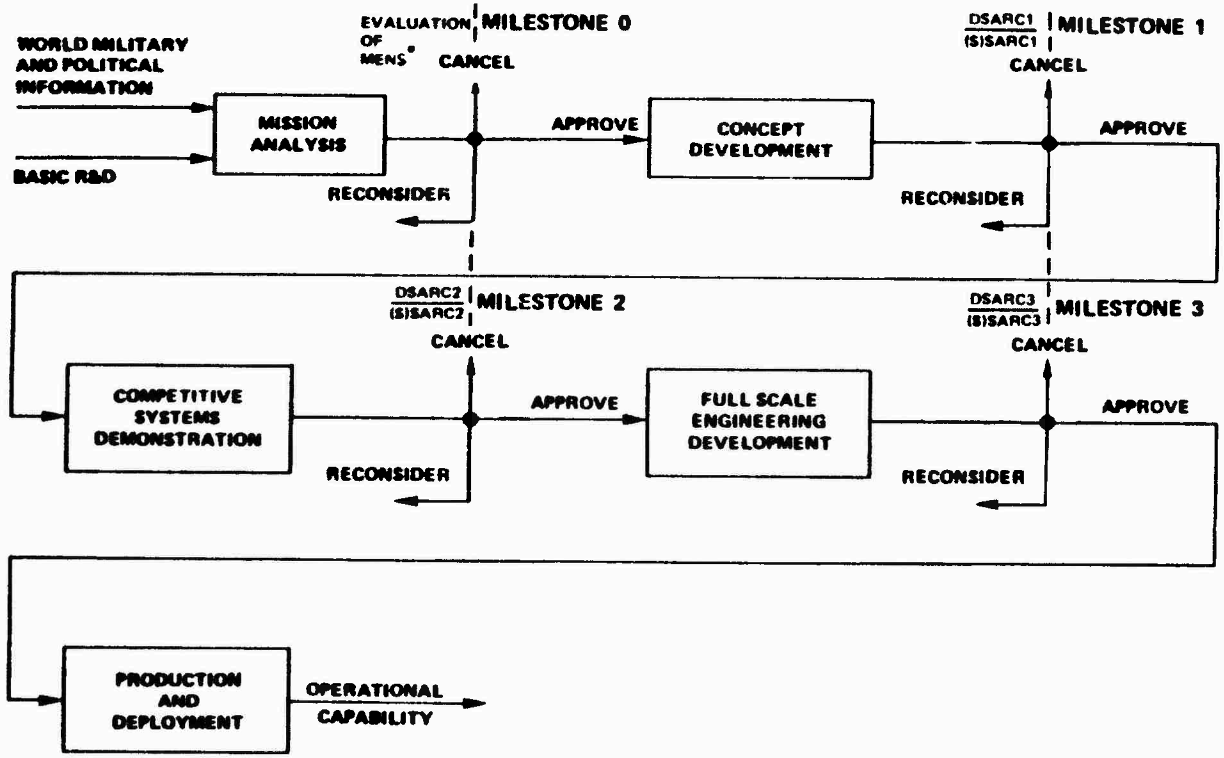
SOURCES OF REQUIREMENTS FOR HFE PARTICIPATION

- THE EXECUTIVE OFFICE OF THE PRESIDENT
  - OMB CIRCULAR A-109
- THE OFFICE OF THE SECRETARY OF DEFENSE
  - DOD DIRECTIVES
    5000.1, 5000.2, 5000.3
  - MIL-H-46855B
  - MIL-STD-1472B
- THE SERVICE BRANCHES
  - ARMY REGULATION 602-1 (HUMAN FACTORS ENGINEERING PROGRAM)
  - NAVY NAVMATINST 3900.9 (HUMAN FACTORS)
  - AIR FORCE AF REGULATION F00-15 (HUMAN FACTORS ENGINEERING AND MANAGEMENT)

Suggestions for
Instructor Comments #3.1

The regulatory structure that should guide the utilization of human factors in the system development process is substantial. The principal mechanism is the linkage of certain HFE activities to the explicit stages of the development cycle. OMB Circular A-109 simply lays the foundation by providing a general specification of the procurement phases. As we shall see, this foundation is susceptible to adaptive interpretation to fix changing priorities at the level of the Department of Defense, the separate service branches, and the nature of the system being developed. A useful perspective of the engineering manager is that the thrust of this set of documents is one that <u>enables</u> the constructive utilization of human factors but does not actually <u>compel</u> compliance, particularly during the early stages of the development cycle. In that sense, the orientation of the present program is to encourage a more intensive link during these early stages where the existing regulations provide mainly what could be called "inferential" support.

MILITARY'S MAJOR SYSTEM ACQUISITION MODEL (OMB A-109)



*NOW CHANGED TO JMSNS.

Suggestions for
Instructor Comments #3.2

While you are probably already familiar with the acquisition cycle, it should be briefly reviewed in order that the relationship between human factors and the development phases can be made clear. While the cycle is constantly subject to revision and is currently being modified, this poses no great problem from the standpoint of human factors. The basic logic of the cycle and the human factors applications described in various directives and standards remains intact.

The graphic presents the acquisition cycle outlined in OMB Circular A-109, which established the guidelines and policies for major Government procurement in 1976. The cycle was developed and promulgated to ensure a more integrated approach to systems development in order to avoid problems of unrealized capability and cost overruns. Thus, the cycle incorporates well-defined development phases and decision points. Starting with Mission Analysis the need for a new system is determined, alternative concepts explored, competitive demonstrations held, finally culminating in full-scale development and production of the system. A memorandum by the Deputy Secretary of Defense (1981) modifies this as it applies to military system acquisition, essentially combining milestones 0 and 1 and increasing the influence of the individual Services in the decisionmaking process. The implementation of these recommendations should have little bearing upon the sequence of human factors engineering efforts.

OVERVIEW OF APPROACH

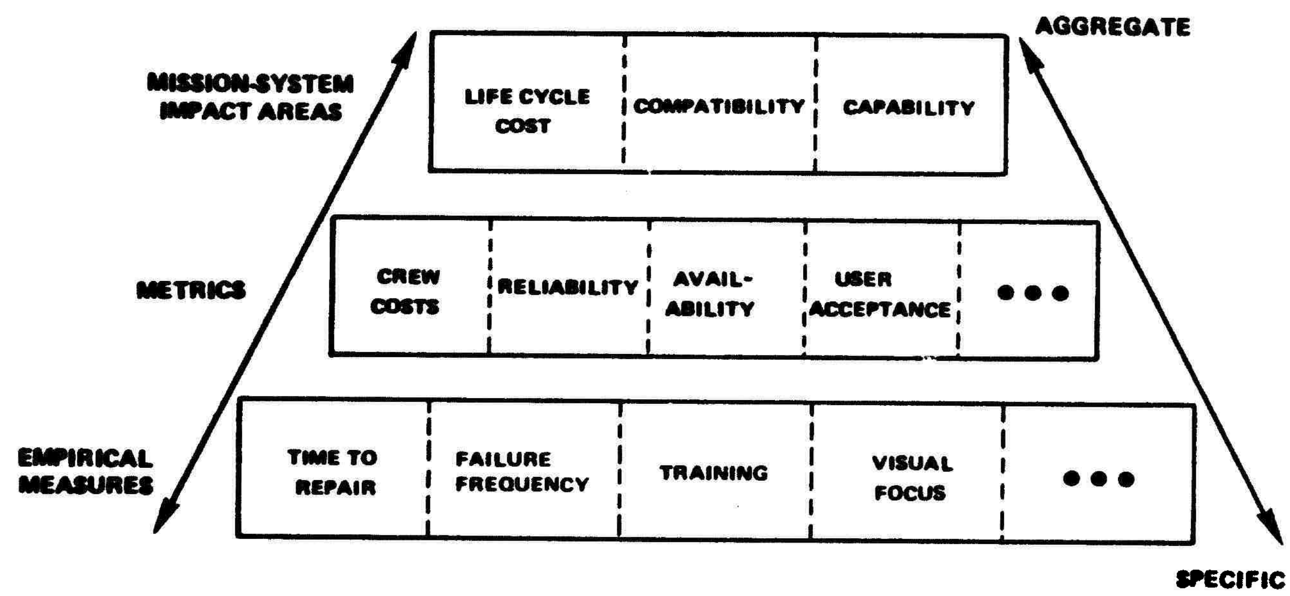
PRINCIPAL HUMAN FACTOR PRODUCT | **IMPACT ANALYSIS METHODOLOGY**

MILIATRY SYSTEM DEVELOPMENT CYCLE PHASES → HUMAN FACTOR ANALYSES AND TESTS → DESIGN RECOMMENDATIONS RELATED TO SYSTEMS ENGINEERING CRITERIA → FORMAL EVALUATION OF HUMAN FACTOR INPUTS

Suggestions for
Instructor Comments #3.3

If the objective is to facilitate the utilization of human factors contributions as early in the system development process as possible and to strengthen the contribution throughout the total sequence, several aspects of the overall structure need attention. On one side, the human factors participants need to organize their work better. To this end, the concept of the human factors Principal Product has been proposed. On the other side, the question of affordability or the benefit-cost analysis of the human factors effort, itself, must be addressed by the engineering managers in an orderly, systematic manner. We have seen that the human factors activity has already been linked to the phases of the development cycle by administrative dictate but the timing and the form of the contribution has been left open. Even more open is the question of the methodology for assessing affordability. Most of the rest of the presentation is dedicated to closing these gaps.

HIERARCHICAL RELATIONSHIP OF IMPACT AREAS, METRICS, & EMPIRICAL MEASURES



Suggestions for
Instructor Comments #3

Before getting into the technical and administrative content of the human factors Principal Product, it is useful to take a quick look at the criterion problem. The graphic shows how well integrated the human factors measures are with those used in the other engineering specialties and in the parent area of systems engineering. The graphic makes explicit the bridge between what is directly measurable and the generic criteria. Thus we can track upward from Training Costs through Crew Costs to Life Cycle Cost and from Ambient Noise Level of User Acceptance to Compatibility. It is, of course, this latter criterion that is the special domain of the human factors specialist and its "equal billing" wit Cost and Capability reflects a recognition of conceptual status that is valid but not often conceded.

We have inserted this measurement-criterion structure here because the concepts are basic to the discussion later on. We can now turn again to the matter of the Principal Product, as such.

PRINCIPAL HUMAN FACTORS PRODUCTS FOR MAJOR SYSTEM DEVELOPMENT PHASES

MAJOR PHASE OF SYSTEM ACQUISITION	PRINCIPAL HUMAN FACTOR R&D PRODUCT
MISSION ANALYSIS PHASE	– DEVELOPMENT OF THE ROLE OF MAN ● MISSION SEQUENCE ● CONTROL LOOP CONFIGURATION ● CREW COMPOSITION AND ASSIGNMENTS
CONCEPT DEVELOPMENT PHASE	– ALLOCATION OF SYSTEM MISSION FUNCTIONS TO MAN ● FUNCTION SHARING ● OVERRIDE CAPABILITIES NEEDED ● LOSS-OF-VIGILANCE FACTORS IDENTIFIED ● JOB SATISFACTION ISSUES SPECIFIED
DEMONSTRATION/VALIDATION PHASE	– TASK ANALYSIS AND DETERMINATION OF HUMAN ENGINEERING REQUIREMENTS ● PEAK WORK LOADS ● SPECIFIC SKILL REQUIREMENTS ● COORDINATION PROBLEMS
FULL-SCALE DEVELOPMENT PHASE	– DESIGN OF THE OPTIMAL MAN-MACHINE INTERFACES ● DISPLAY DESIGN ● CONTROL-DISPLAY COMPATIBILITY ● WORK SPACE LAYOUT ● OPTIMUM ENVIRONMENT GIVEN OPERATIONAL CONDITIONS

Suggestions for
Instructor Comments #3.5

The link between Principal Product and development phase can now be made more explicit. The logic of the sequence is as solid as it is for the other design inputs. The technical topic coverage is illustrated in the graphic, and we can usefully elaborate on the Product for each phase in turn.

Mission analysis. Although there rarely is sufficient human factors input in this phase of system development, human factors participants should contribute substantially at this point. Their job is to assess the potential impacts of optional system configuration upon habitability, compatibility, and other performance-related factors. The Principal Product will be a role-of-man statement, which will project crew composition and division-of-labor (e.g., operation, maintenance, analysis, decisionmaking) among and within crews. In defining that role, all functions of the system must be defined for the various system options.

Concept development. Once the system has been formally approved by the DOD, a program manager (PM) and staff are appointed; they will be responsible for initial systems planning (projected costs, logistics, risks, and tradeoffs for the design options). The resulting documentation for the (S)SARC and DSARC reviews will be the Decision Coordinating Paper (DCP) and Integrated Program Summary (IPS), to be updated at each subsequent milestone review.

Suggestions for
Instructor Comments #3.5
(CONTINUED)

The human factors role is the <u>allocation of man-machine functions</u> (described in Module 2). Criteria are established for each function, and alternative allocations are matched against such criteria. In this way, the system will be designed efficiently in regard to the manner in which operators/maintainers and equipment share the performance of systems functions.

<u>Demonstration/validation</u>. In this phase competitive demonstrations are held, and the human factors effort narrows to the more detailed human engineering "nuts and bolts" tasks. Mock-up walk-throughs, workflow analyses, task analyses, time-line analyses, simulation (see Module 2), and development operational testing constitute the basic efforts here. From these analyses will emerge the data which form the basis for the human engineering requirements.

<u>Full-scaled development</u>. This phase requires the firming up of the design plan and the tailoring of prototypes to requirements, standards, and specifications. The human factors engineering work involves the "fine tuning" of system interfaces in response to prototype changes and data from continuing testing.

PRINCIPAL HUMAN FACTOR PRODUCT CONTENTS

- CHECK-OFF LIST OF CRITICAL HUMAN FACTOR ISSUES
- EMPIRICAL AND/OR ANALYTICAL FINDINGS FOR HUMAN FACTOR ANALYSIS, DESIGN, TEST, AND EVALUATION TECHNIQUES
- PRELIMINARY TRANSLATION OF ACTIONS IN TERMS OF HUMAN FACTOR AND SYSTEM ENGINEERING IMPACT METRICS AND CRITERIA
- RECOMMENDED HUMAN FACTOR RELATED ACTIONS AND SPECIFICATION OF CASES WHERE IMPACT ASSESSMENT MIGHT BE REQUIRED
- HUMAN FACTOR MANAGEMENT PLAN UPDATE

Suggestions for
Instructor Comments #3.6

The ideal Principal Product will contain more than a set of design recommendations. The graphic reveals a generalized Table of Contents. The technical matters come first, but note that the Products should contain (or cite the location of) actual data in the form of findings from analyses or studies. Design recommendations, as such, are incorporated within the third bullet. The fourth and fifth bullets refer to administrative matters. The fourth is, in a sense, a concern for corrective feedback. It is saying to the engineering manager: Here are the projected next steps--more analyses and studies--which should be given a hard look from the standpoint of affordability or expected pay-off vs. cost. The plan update would also cover such matters as the scheduling of future actions and the recruitment of additional expertise, if required.

THE ROLE OF THE HUMAN FACTORS PRACTITIONER

- TECHNICAL –
  - ROLE OF MAN—INPUTS TO CONFIGURATION CONCEPT
  - ALLOCATION OF FUNCTIONS—INPUTS TO BASIC DESIGN
  - TASK ANALYSIS—INPUTS TO MANPOWER, PERSONNEL, AND TRAINING DECISIONS
  - INTERFACE ANALYSIS—INPUTS TO DETAILED DESIGN
- ADMINISTRATIVE/MANAGERIAL SUPPORT –
  - RESEARCH CURRENCY—TECHNOLOGY BASE INPUTS
  - APPLICATIONS CURRENCY—LESSONS LEARNED INPUTS
  - OPERATIONS CURRENCY—USER COMPATIBILITY INPUTS
  - METHODS CURRENCY—TEST DESIGN INPUTS

Suggestions for
Instructor Comments #3.7

This graphic also emphasizes the dual nature of the contribution: technical and administrative. Just as the Principal Product has these two components, the practitioner must be able to provide inputs in both areas. The emphasis is on <u>how</u> the practitioner can support the broader functions of the PM and the other engineers. One way is to be able to tap the knowledge base for relevant basic and non-system-specific research findings. Another way is to be aware of the systems work going on in related areas and to transmit the insights gained from his or her own work to colleagues in such related areas. The practitioner should also be able to represent the ultimate user on the basis of a good knowledge of operational conditions and user needs and attitudes. Lastly, the practitioner should support test design--even if the tests to be conducted are not intended to measure human factors variables.

AN EXAMPLE
OF HUMAN ENGINEERING REQUIREMENTS IN A SOW

<table>
<tr><td rowspan="2">DATA ITEM DESCRIPTION</td><td colspan="2">2. IDENTIFICATION NO(S).</td></tr>
<tr><td>AGENCY</td><td>NUMBER</td></tr>
<tr><td>1. TITLE</td><td>DOD</td><td>DI-H-7056</td></tr>
<tr><td rowspan="4">3. DESCRIPTION/PURPOSE

This document provides a source of data to evaluate the extent to which equipment having an interface with operators meets human performance requirements and human engineering criteria.</td><td colspan="2">4. APPROVAL DATE
1 June 1979</td></tr>
<tr><td colspan="2">5. OFFICE OF PRIMARY RESPONSIBILITY</td></tr>
<tr><td colspan="2">ARMY/MIRADCOM</td></tr>
<tr><td colspan="2">6. DOC REQUIRED</td></tr>
<tr><td rowspan="3">7. APPLICATION/INTERRELATIONSHIP

This DID replaces DI-H-2107, DI-H-3261A, DI-H-4605, UDI-H-21272 and UDI-H-21385.

This DID is primarily applicable to work tasks delineated in paragraph(s) 3.2.1.2, 3.2.1.3, 3.2.1.4, and 3.2.2 of MIL-H-46855B.</td><td colspan="2">8. APPROVAL LIMITATION</td></tr>
<tr><td colspan="2">9. REFERENCES (MANDATORY AS CITED BLOCK 10)
MIL-H-46855B
MIL-STD-1472</td></tr>
<tr><td colspan="2">MCSL NUMBER(S)</td></tr>
</table>

10. PREPARATION INSTRUCTIONS

10.1 *General*. The Human Engineering Design Approach Document – Operator HEDAD-O* shall be prepared which describes the layout, detail design and arrangement of crew station equipment having an operator interface; it shall also describe operator tasks associated with the equipment. The HEDAD-O shall describe the extent to which the human performance requirements, MIL-STD-1472 and other applicable human engineering documents specified in the contract have been incorporated into the layout, design and arrangment of equipment having an operator interface. Operator task analysis results shall be presented as part of the rationale supporting the layout, design and integration of crew station equipment.

10.2 *Content Requirements*. HEDAD-O shall consist of the following crew station and operator-related information:

1) List of each item of equipment having an operator interface and a brief statement of the purpose of each item of equipment. Separate lists shall be provided for each operator's station.

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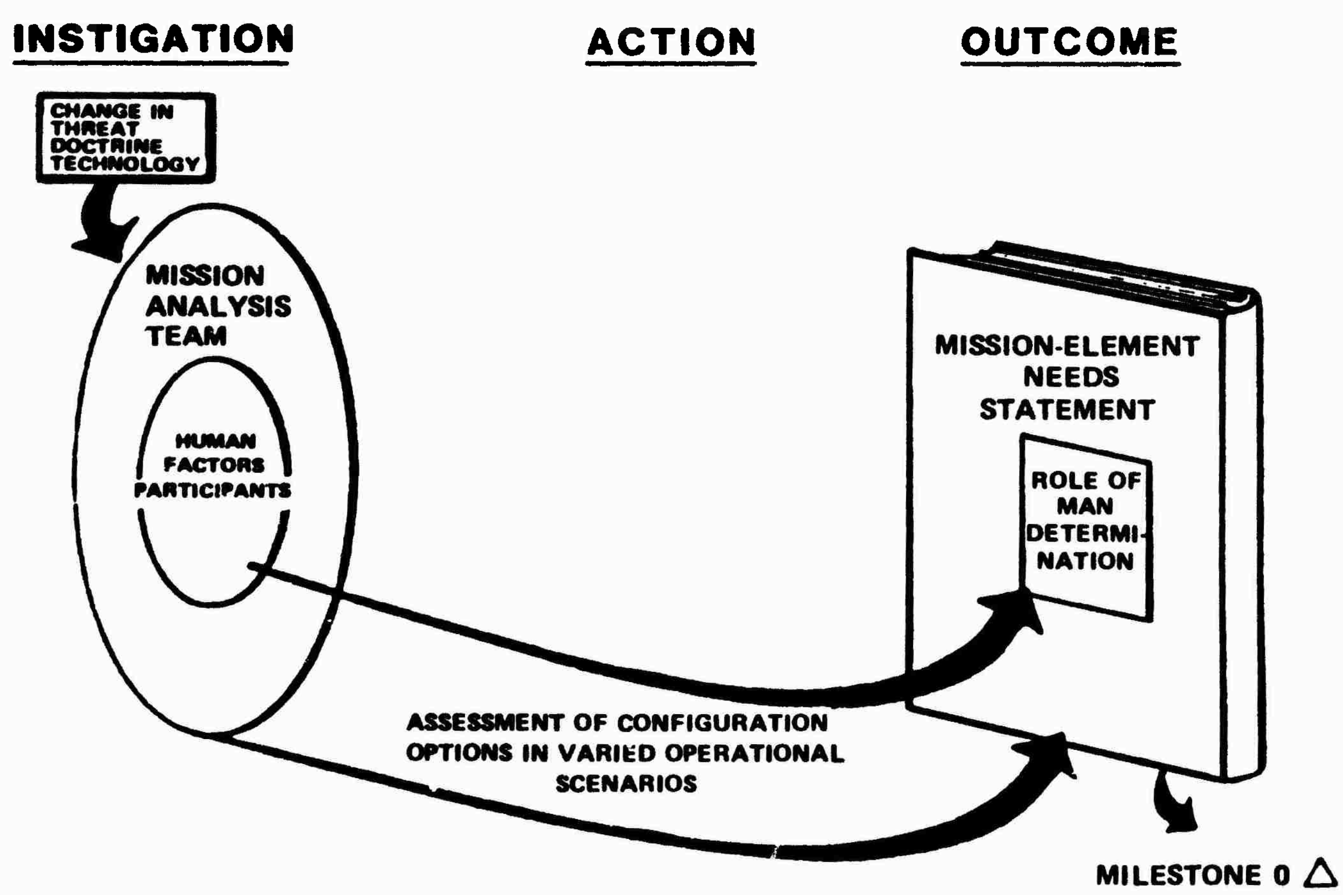
*HUMAN ENGINEERING DESIGN APPROACH DOCUMENT-OPERATOR.

Suggestions for
Instructor Comments #3.8

To make the propositions about the practitioner's role as concrete as possible, this graphic is included. It indicates the kinds of requirements that will be "laid-on" prospective contractors, and highlights the point that someone on the PM staff will be needed to evaluate the responsiveness of the competing contractor's proposals and compliance with such specifications once the contract is awarded.

HUMAN FACTORS PRINCIPAL PRODUCT

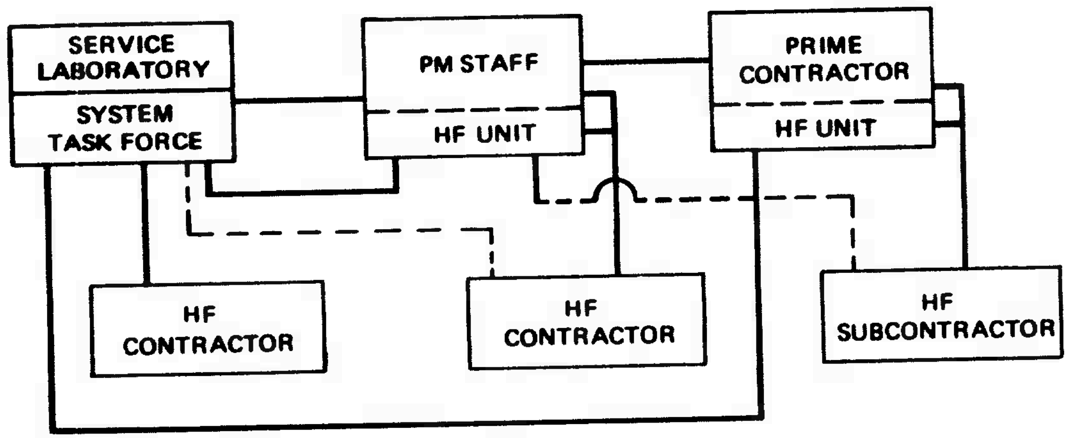
FIRST PHASE: MISSION ANALYSIS



Suggestions for
Instructor Comments #3.9

Having looked at the role of the individual practitioner, we can now explore some of the organizational implications that surround the fulfillment of that role. This graphic shows in a dynamic way the involvement of human factors specialists in the first stages of the development cycle. You can note the symbolic inclusion of the Role of Man determination as a part of the Mission Element Needs Statement. The main point, however, is that the human factors participants are shown as an integral part of the Mission Analysis Team. Legitimate questions are: Where do these participants come from? Where does the engineering manager go to get help at this stage? The ideal answer is that these participants should come from the appropriate in-service laboratory: the Army Research Institute or the Army Human Engineering Laboratory, the Naval Research Laboratory or the Navy Personnel Research and Development Center, and the Air Force Aeromedical Laboratory or the Human Resources Laboratory. In some cases, the organization that conducts the Mission Analysis phase has resident human factors personnel. This is the case, for example, at the Naval Air Development Center. Otherwise, it is also possible to turn to contractor organizations that can provide on-site technical services of this sort. The Service laboratory senior R&D staff can provide lists of contractors that could provide qualified individuals.

HYPOTHETICAL HFE ORGANIZATIONAL PATTERN DURING THE DEMONSTRATION/VALIDATION PHASE OF MAJOR SYSTEM DEVELOPMENT



Suggestions for
Instructor Comments #3.10

For the Concept Development phase, the organizational relationship would be much the same as for the Mission Analysis phase except that engineering management would shift to a Project Management team. If we skip over to the Demonstration/Validation phase, the relationship can get more complicated as illustrated by the graphic. The diagram shows what could be regarded as a set of mix-and-match options. In that sense, it would be unlikely that all the components shown in the diagram would ever be involved in any single system development effort. Frequently, the Service laboratory would have their system task force as an integral part of the PM's staff, which would make it equivalent of the HF unit shown on the diagram. This unit would control any HF contractors working directly for the PM as well as the HF unit in the prime contractor's organization and any subcontractors that the prime might see fit to engage. The in-service group presumably would have had continuous involvement in the preceding steps and could thus exercise such a supervisory function very effectively.

MEASUREMENT OF HUMAN FACTORS CONTRIBUTION: IMPACT AREAS

- **CAPABILITY IMPACT AREA**

THE ABILITY OF THE SYSTEM TO SUCCESSFULLY PERFORM ITS MISSION

- AVAILABILITY
- READINESS
- EFFECTIVENESS

- **COST IMPACT AREA**

THE TOTAL RELEVANT, VARIABLE COST ASSOCIATED WITH THE SYSTEM MISSION OVER ITS LIFE CYCLE

- RESEARCH AND DEVELOPMENT
- ACQUISITION INVESTMENT
- OPERATING AND SUPPORT

- **COMPATIBILITY IMPACT AREA**

THE OVERALL COMPATIBILITY OF THE SYSTEM DESIGN WITH ITS OPERATORS AND MAINTAINERS

- PHYSICAL
- PHYSIOLOGICAL
- PSYCHOLOGICAL

Suggestions for
Instructor Comments #3.11

Logistics analyses and other sub-engineering specialties are increasingly incorporated into the system design process because PMs and higher level engineering managers have been convinced of their value by rigorous evaluation procecures. Although there exists no need to evaluate every human factors contribution within a cost-benefit framework, it is important to point out that human factors people are both concerned with the costs of implementing their recommendations and able to weigh the resulting human-related impacts against such costs. The technique to be discussed is called Impact Analysis. Basically, the documented human factors product for any development phase should include information aoout human factors issues, deficiencies, and findings (tests, etc.). Once a human factors problem is selected, this information can be translated into the cost, capability, and compatibility impacts to be evaluated using the impact analysis methodology. After the alternative solutions, baseline system, reference system(s), and impact areas/ measures have been defined, the appropriate model is selected to estimate the costs and benefits for each of the alternatives.

IMPACT ASSESSMENT METHODOLOGY

FORMULATING THE IMPACT ANALYSIS (DERIVED FROM PRINCIPAL HFE PRODUCTS)

1. ESTABLISHING THE PROBLEM, GOALS, AND CRITERIA
2. DEFINING THE ALTERNATIVE SOLUTIONS
3. SPECIFYING THE BASELINE
4. PREPARING THE SYSTEM DEFINITION STATEMENT (REFERENCE SYSTEM(s))
5. SELECTING THE IMPACT AREAS, METRICS, AND PERFORMANCE MEASURES

CONDUCTING THE ANALYSIS

6. SELECTING/CONSTRUCTING THE IMPACT ASSESSMENT MODEL(S)
7. COLLECTING AND PROCESSING THE DATA
8. SETTING THE CONVENTIONS FOR THE ANALYSIS
9. ESTIMATING AND EVALUATING THE IMPACTS

PREPARING AND INTERPRETING THE RESULTS

10. PRESENTING THE RESULTS, ASSOCIATED UNCERTAINTIES, AND BOUNDING CONDITIONS

Suggestions for
Instructor Comments #3.12

Impact Assessment is an off-shoot of Cost-Benefit Analysis that provides the means of asking and answering the question: What would have been the sequence of not having the HF Product? What could the wrong decision have cost?

The graphic shows the ten basic steps involved in conducting an Impact Assessment. Some elements have already been touched upon but the best way to illustrate the procedure is with some concrete, if hypothesized, examples. For instance, let us assume that the system in question is a main battle tank. The immediate goal (Step 1) is to enhance first round hit probability. The alternative solution (Step 2) might include a high performance turret (fast traverse//fast elevation/depression) and a laser gunsight, or both. The baseline (Step 3) would be defined by existing electromechanical actuators. The reference system (Step 4) would be the turret configuration and sighting equipments on the present main battle tank. In this case, the metrics (empirical measurements) (Step 5) would include the tracking and aiming performance of typical gunners. This last step and Steps 6 through 10 require more elaboration.

SIMPLE ILLUSTRATION OF AN IMPACT ASSESSMENT MATRIX

CANDIDATE HUMAN FACTORS-RELATED ACTIONS	METRICS AND MEASURES						
	QUANTITATIVE				QUALITATIVE		
	COSTS TO DEVELOP AND IMPLEMENT ACTIONS ($)	COST SAVINGS OR AVOIDANCE ($)	SYSTEM AVAILABILITY (%)	. . .	USER ACCEPTANCE (NORMALIZED ORDINAL SCALE UNITS)	MORALE (NORMALIZED ORDINAL SCALE)	. . .
HF_1							
HF_i							

NOTE: DIMENSIONS OR UNITS OF MEASURE ARE SHOWN IN ( ).

Suggestions for
Instructor Comments #3.13

Thus, when we get to the matter of measures (Step 5), we need to show more breadth. This graphic reminds us that we need to always incorporate the full range of measures--Cost factors and Compatibility factors--as well as Capability, as represented by tracking and aiming accuracy.

ALTERNATIVE MODELS FOR USE IN IMPACT ASSESSMENT

- MATHEMATICAL MODELS
- COMPUTER SIMULATION MODELS
- EXPERIMENTS
- OPERATIONAL GAMES
- SURVEYS/GROUP DECISIONS
- VERBAL MODELS
- PHYSICAL MODELS

Suggestions for
Instructor Comments #3.14

Step 6 of the impact assessment methodology is, in some ways, the most crucial and the most complicated of the 10 steps. It involves the selection of a model (or several models) for conducting the particular analysis relative to the attributes of a given system, the human factors issues, and the phase of system development.

The selection process is complicated by the fact that there is no one model or model type that is appropriate or best for analyzing all the human factors issues throughout the system development phases. Consequently, we cannot recommend any one model over any other for this step.

Because there are a number of models that can be used in the framework, it is useful to have, at least, a way to classify model types in terms of their basic characteristics. The model classes are not mutually exclusive; that is, a model assigned to one class can also have some of the characteristics of models in other classes. The class name indicates the basic or principal characteristics of--and the means used by--the model(s) to analyze the issues under consideration. We have identified seven model classes to catalog the types of models that are potentially useful to human factors analysis, and these are presented in the graphic.

A suggested set of selection criteria that can be used to identify the most suitable model to use in a given setting includes:

Suggestions for
Instructor Comments #3.14
(CONTINUED)

1. Validity (Does the model reproduce or realistically represent the functional relationships under consideration?)

2. Relevance (Does the model deal explicitly with the human factors issues under analysis?)

3. Cost (Is the model very expensive to construct or use?)

4. Non-Trival (Does the model provide substantive insights into the process under analysis?)

5. Feasibility (Can the model be used? Are the data required available? Are the staff with the required skills available? Is there sufficient time to use the model?)

6. Reliability (Does the model give consistent results under different circumstances?)

7. Acceptability (Can the model results be communicated successfully to the system designers and engineering managers? Put another way, can or will the designers use the model results?)

F/A-18 CASE STUDY:

PHASE :	FULL-SCALE ENGINEERING
PRINCIPAL HUMAN FACTOR PRODUCT :	MAN-MACHINE INTERFACE
HUMAN FACTOR ISSUE :	HIGH PROBABILITY OF FOOT CONTACT DURING EJECTION
IMPACT AREAS: PRIMARY : SECONDARY :	 COMPATIBILITY COST
ALTERNATIVES	A_0 – THE BASELINE DESIGN (STATUS QUO OR "DO-NOTHING" OPTION) A_1 – CHANGE THE CREW STATION GEOMETRY (RAISE THE INSTRUMENT PANEL, LOWER THE HEELREST LINE) A_2 – CRUSHABLE ENERGY ABSORBER A_3 – HINGED KICK PANEL A_4 – PASSIVE TOE GUIDE

F/A-18 CASE STUDY:

IMPACT ASSESSMENT SUMMARY

	ALTERNATIVES	IMPACT MEASURES			
		AVIATOR COMPATIBILITY	SYSTEM COST	PERFORMANCE WEIGHT IMPACT	COST TO IMPLEMENT
A_0	BASELINE	20 TO 70% NON-COMPATIBLE	BASELINE; NO CHANGE	NONE	NONE
A_1	CHANGE CREW STATION GEOMETRY	100% COMPATIBLE	HIGH IMPACT	NA	VERY HIGH
A_2	CRUSHABLE ENERGY ABSORBER	REDUCE TO $\cong$ 10% NON-COMPATIBLE	LOW	4 LB	LOW
A_3	HINGED TOE GUIDE	100% COMPATIBLE	MEDIUM	5 LB	MEDIUM
A_4	PASSIVE TOE GUIDE	100% COMPATIBLE	LOW	$<$.1 LB	LOW

Suggestions for
Instructor Comments #3.15

To illustrate all the steps in the Methodology we can now return to some concrete examples. In fact, two detailed case studies were conducted as part of the project that led up to this course. One was done on the F/A-18. The first graphic illustrates the summary outcome of the first steps. The underlying issue was pilot safety during an in-flight ejection from the cockpit. A physical model could be used in this case because of the existing anthropometric data on pilots. The results (Visual 3.15b) show that the engineering design decision could be rendered unequivocal. The baseline alternative was simply unacceptable. The passive toe-guide removed the problem at the lowest net cost and lowest negative performance impact. The cost of the study and analysis, as such, could be estimated to be no more than $1,000 if it had been done by either the NADC in-house human factors staff or by the prime contractor. The dollar value of increasing the available pool of pilots was not estimated but the cost avoidance from just a single instance of physiological damage to a pilot would be at least $100,000. Thus a very conservative estimate of return-on-investment for the safety study would be 100:1.

MANEUVER CONTROL SYSTEM CASE STUDY:

SELECTED COMPONENTS OF IMPACT ANALYSIS

PHASE :	MISSION ANALYSIS
PRINCIPAL HUMAN FACTOR PRODUCT :	ROLE OF MAN DETERMINATION
HUMAN FACTOR ISSUE :	DEDICATED VS. NON-DEDICATED USER
IMPACT AREAS: PRIMARY : SECONDARY :	 COST COMPATIBILITY
ALTERNATIVES	A. – MINIMAL, SYSTEM SPECIFIC SOFTWARE B. – EXTENSIVE, GENERIC SOFTWARE

MANUEVER CONTROL SYSTEM CASE STUDY:

METRICS	Δ(ALT. A – ALT. B)	
COST (HIGH IMPACTS)		
● RESEARCH AND DEVELOPMENT		
(PROTOTYPE)	(500,000)	
(TEST)	(100,000)	
(R & D TRAINING)	(100,000)	
OTHER	(150,000)	
		(850,000)
● ACQUISITION		
(PURCHASE)	(5,000,000)	
(ALL)	16,950,000	
		11,950,000
● OPERATING AND SUPPORT		
PERSONNEL	20,000,000	
(SPARES)	(800,000)	
		17,200,00
TOTAL LIFE CYCLE COST ADVANTAGE OF SET B (CONSTANT 1980 DOLLARS)	= 28,000,000	

COMPATIBILITY (B IS PREFERRED)

- NON-DEDICATED USER COMPATIBILITY YIELDS INCREASED SYSTEM READING
- COMPATIBLE WITH A WIDER RANGE OF OPERATOR SKILLS

Suggestions for
Instructor Comments #3.16

The second case study involved the analysis of the role of man in the operation of a hypothesized C^3I system for use in ground combat at the platoon level and above. Similar computerized information processing systems have already been deployed in prototype versions by the Army. The main question was whether or not a substantial investment in software development that would make the system usable by non-specialist personnel would pay off. Using reasonable but unvalidated estimates of cost components, a gross advantage of over $28M could be assigned to the option in which the system software would permit non-specialist operators to use the system. If such a study were to be done in the most rigorous manner using an empirical simulation model as opposed to the abstract mathematical model used in the case study, the study cost might be as high as $40,000, which would yield a benefit cost ratio of over 700:1.

Suggestions for Instructor's Closing Comments for Module #3

This module has portrayed the military systems development cycle and the formal/informal documents, management issues, and potential payoff related to the human factors effort throughout the different cycle phases. The existing guidelines and directives provide a solid basis for human factors in development, but proper management is a crucial ingredient in implementing such participation. System developers can contribute to and benefit from human factors by (1) addressing predevelopment human performance questions realistically, (2) developing an in-house human factors group (at the least, a close liaison with a laboratory or consultant), and (3) ensuring this group an effective role in the development process and helping to define that role carefully. Finally, the potential payoff of this kind of effort is discussed within a cost-benefits framework. This methodology is useful in demonstrating past human factors contributions and should be valuable in the decisionmaking process, itself.

SUGGESTIONS FOR A COMBINATION LECTURE/WORKSHOP

Introduction

Combining a lecture with a workshop offers the advantage of both the presentation of new material and active problem-solving by students. The approach also utilizes the expertise of students and, if conducted properly, provides performance feedback and the realistic resolution of whatever problems are addressed. Such an approach also would be likely to appeal to a student population geared to active, hands-on work. Of course, a major constraint on the use of a workshop is the question of sufficient time.

Assuming that the students are fairly naive about human factors and the role of this discipline in systems acquisition, they should attain the following from the lecture/workshop:

- The ability to ask the right human factors questions at the appropriate time.
- An understanding of the applicability of human factors analyses to such questions.
- An increased knowledge of how to evaluate the human performance characteristics of a system.
- An increased ability to interpret human factors requirements in design terms.
- An understanding of manpower, personnel, and training tradeoffs.
- An understanding of the consequences of failure to incorporate human factors in system design.

Lecture

The lecture portion would be extracted from the modules and tailored to the backgrounds and needs of the particular target audience. Included among the material presented should be the following:

- The traditional human factors problems in military systems.
- The more recent problems which have evolved.
- The differences and similarities among systems regarding operations and maintenance human factors problems.
- What human factors guidelines and requirements mean in terms of system design.
- The logic of human factors in the development cycle.
- The testing and evaluation of human factors during development.

Workshop

(One to two hours per exercise.) The best approach would be to confront the students with realistic problems which mesh closely with those that systems program staffs actually encounter. Such problems must be realistic, but at the same time they should be sufficiently limited in scope that students can deal with them in a short timespan. The basic approach recommended is that of breaking the class up into teams and having them solve human factors-related problems in military systems. The steps are as follows:

1. Selection of Teams--This should be done in such a way as to maximize the backgrounds/expertise of participants and make the process manageable. The manner in which this is done will depend in large part upon the nature of the problem(s) dealt with.

2. Assignment of Problem(s)--A large number of options exist; a few possible types of problems, as well as the manner of their assignment, are shown below.

   Optional Types of Problems:

   (a) Teams are presented with a statement of work (SOW) and human factors requirements. The task is to do preliminary design of a system or subsystem, depending upon the acquisition phase and system chosen. For example, in a recent workshop sponsored by the public utilities, engineering managers were set the task of laying out the control room of a nuclear power plant. The function and quantity of displays and controls were a fixed input to the exercise. After a team effort of several hours, each team's product was displayed and criticized by other teams.

   (b) Teams are given the basic design of a subsystem and a set of revised requirements. The task is to decide whether changes are viable, and if so, how those changes are to be made. For example, an interesting case might be the redesign of the crewstation layout for a non-U.S. armored vehicle. There has been much discussion recently of the relative advantages of design simplicity that are allegedly present in systems deployed by potential enemies. Using such materials as sketch layouts

of the commander's station in a Soviet T-48 tank with instructions to improve the design to enhance operator performance would enliven the exercise by confronting the team members with the opportunity to challenge a whole alternative design philosophy as compared to just specific details of design.

(c) Teams are given a synoptic field report that summarizes user complaints about a particular system (e.g., an attack helicopter). The task is to prepare a task order for the human factors workers (either in-house or contractor) in such a way that the deficiencies will be corrected without instigating other new problems such as escalation of operating costs.

(d) The teams are each given three resumes that represent applicants for the position of the head human factors person on the PM's staff. The project is the development of a major ballistic missile system so the total in-house HFE team might number as many as 16 professional-level personnel. The task is to evaluate the candidates and select one for the position.

(e) The team is given the MENS for a major airborne ECM system. The task is to develop an HFE staffing plan for the two-year period set aside for the preparation of the DCP. The instructor should encourage discussion among team members of the option of in-house vs. contractor staffing of the positions needed.

(f) The team is given a synoptic system description and SOW that is to be a part of a substantial RFP (e.g., a three-men submarine for use by UDTs). The task is to decide how many rating points (i.e., out of 100) to assign to the HFE component for proposal evaluation purposes.

Ways of Assigning Teams:

(a) All teams get the same system and human factors problem; their different approaches to solving the problem will be of major interest.

(b) Different teams are assigned both different systems and different types of human factors problems. The purpose will be that of comparing the problems and their solutions across different systems.

(c) Some teams are asked to solve problems, while others are asked to evaluate the solutions from both an engineering and human factors point of view.

3. Discussion of Solution(s)--Depending upon the nature of the problem and the manner of team assignments, a period of time will be devoted to discussion of the manner in which problems were solved. To the extent possible, all relevant questions of tradeoffs, capability, reliability, life-cycle costs, etc. will be dealt with.

Materials

Since the workshop exercises will involve the use of design specifications and human factors requirements, proper documentation will have to be constructed in a handout form--for example, an actual or simulated SOW. In addition, exercise summary forms

should be given students. Finally, since problem-solving will entail the making of at least rudimentary designs, such materials as drafting pens/pencils, triangles, compasses, templates, T-squares, rules, and drafting boards probably should be provided. These would not only be functional, but they would add to the authenticity of the exercises as well.

Special Considerations

Obviously, the characteristics of the audience will play a significant role in the way in which the workshop approach will be conducted. Subject to modification when more is known about the target audience, the following considerations seem reasonable:

- Diversity of student experience should be utilized to the extent possible.
- The problems should be highly realistic; otherwise, they will be rejected.
- Human factors inputs should be as concrete as possible.
- The detail in students' sketches should be restricted to a practical level.